chapter

10 Circulatory System

In this chapter

Your circulatory system moves blood throughout your body. It carries nutrients to cells, wastes away from cells, and chemical messages from cells in one part of the body to distant target tissues. It distributes heat throughout the body and, along with the kidneys, maintains levels of body fluid.

Your circulatory system has 96 000 km of blood vessels to sustain your 100 trillion cells. No larger than the size of your fist and with a mass of about 300 g, the heart beats about 70 times/min from the beginning of life until death (**Figure 1**). During an average lifetime, the heart pumps enough blood to fill two large ocean tankers.

Every minute, 5 L of blood cycles from the heart to the lungs, picks up oxygen, and returns to the heart. Next, the heart pumps the oxygen-rich blood to the tissues of the body. The oxygen aids in breaking down high-energy glucose into low-energy compounds, which releases energy within the tissue cells. The cells use the energy to build new materials, repair existing structures, and for a variety of other energy-consuming reactions. Oxygen is necessary for these processes to occur, and the circulatory system plays a central role in providing that oxygen.

The circulatory system is also vital to human survival because it transports cellular wastes and helps defend against invading organisms. It permits the transport of immune cells throughout the body. You will learn about the immune system in the next chapter.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. People with heart problems often experience a racing and pounding heart even after mild exercise. Why does this occur?
2. Elite athletes literally have "big hearts." How would the resting heart rate of someone with cardiovascular disease compare to that of an athlete? Suggest a reason for the difference.
3. If scientists wanted to grow a heart, would it be best to obtain cells from the individual who had the heart problem or another individual? Explain.
4. Although scientists have successfully grown cells to form certain heart components, these tissue cultures lack the arteries and veins found in a normal heart. Why are blood vessels necessary?

Career Connections:
Cardiology Technologist, Registered Nurse

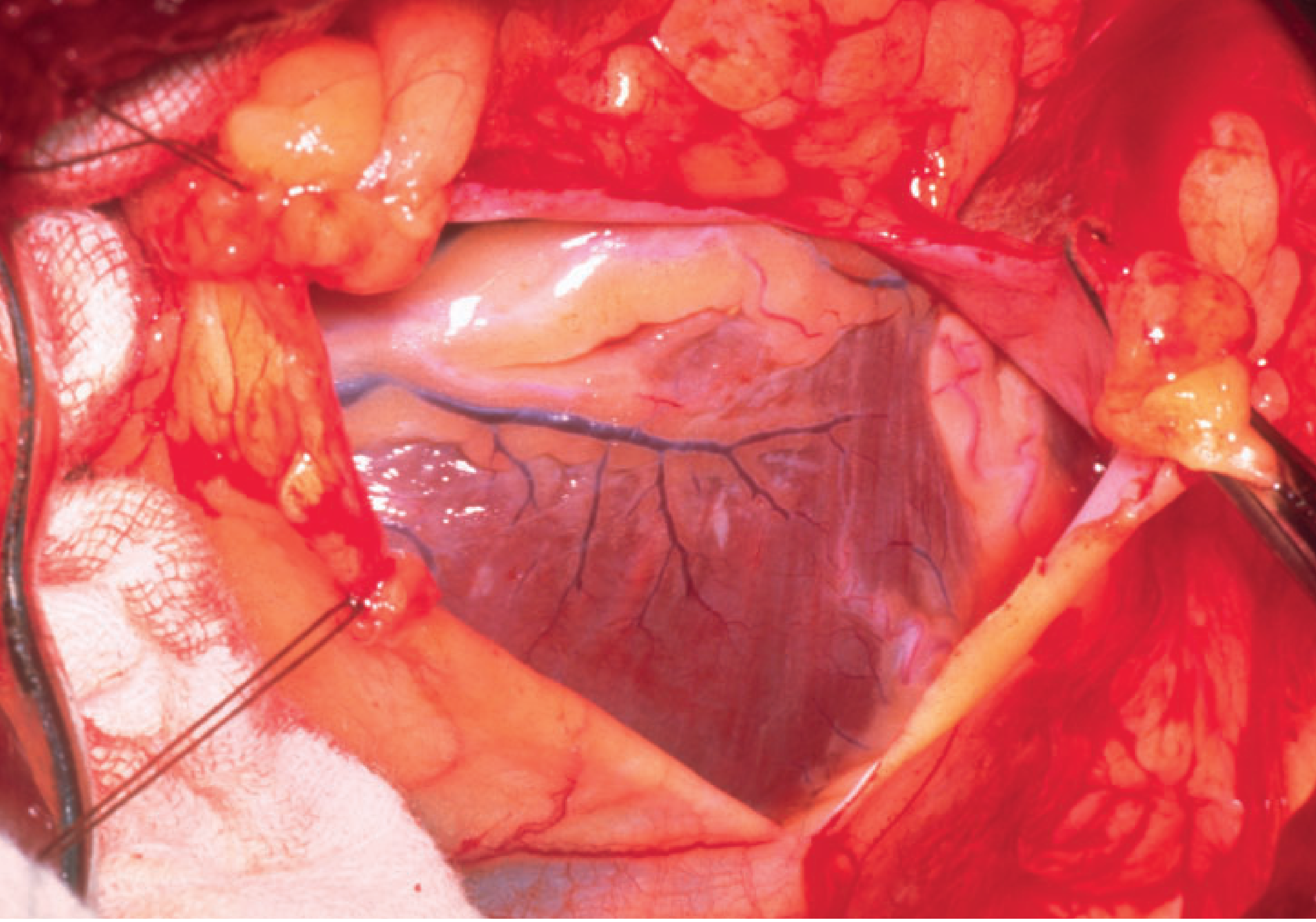


Figure 1
In this photo of a heart during surgery, you can see the coronary artery that supplies the muscle cells of the heart with the oxygen and nutrients they require. A blocked coronary artery can greatly reduce the ability of the heart to function.

Exploration — *Listening to Heart Sounds*

Medical workers use stethoscopes to measure blood pressure and to listen to the heart, lungs, and intestines. You will use a stethoscope to listen to your heart.

Disinfect the earpieces of the stethoscope with rubbing alcohol before and after use.

- Place a stethoscope on your own chest and listen for a heart sound (**Figure 2**). Locate the area where the heart sounds are loudest and clearest.
- After 1 min of moderate exercise (e.g., walking on the spot), listen for your heart sounds again.

(a) Draw a diagram of a chest showing where you located the clearest sound.
(b) Did the sound of your heartbeat change after exercise? Describe what differences you heard.

Figure 2
A stethoscope

10.1 Blood Vessels

Figure 1
William Harvey (1578–1657)

The ancient Greeks believed that the heart was the centre of human intelligence, an "innate heat" that generated four humours: black and yellow bile, phlegm, and blood. Galen, the personal physician of Roman emperor Marcus Aurelius in the second century C.E., influenced early physiology. Although he provided many enlightening theories, Galen is best known for steering scientists in the wrong direction. Galen believed that blood did not circulate. Although he believed that blood might ebb like the tides, he never thought of the heart as a pump. Galen's theory was generally accepted until the 17th century. Some science historians have suggested that his failure to consider the pumping action of the heart could be attributed to a lack of a technical model: the water pump had not been invented when Galen applied his theory.

William Harvey (1578–1657), the great English physiologist (**Figure 1**), questioned Galen's hypothesis. Harvey, like many Europeans during that period, was influenced by the astronomer Galileo. Galileo's new principles of dynamics became the foundation of Harvey's work. By applying Galileo's theories of fluid movement to blood, Harvey reasoned that blood must circulate.

Harvey attempted to quantify the amount of blood pumped by the heart each minute. He began his research by dissecting cadavers and observing blood vessels. Using mathematics, he calculated that the heart contains approximately 57 mL of blood. Harvey then concluded that 14.8 L must be pumped from the heart each hour. However, much less blood could be found in the body; the heart must be pumping the same blood over and over again. Harvey's estimates were at best conservative—he greatly underestimated the capacity of the heart to pump blood. However, by using empirical data, Harvey tested and challenged a theory that had been accepted for 1400 years.

Although William Harvey was convinced that blood must pass from the arteries to the veins, there was no visible evidence of how this was accomplished. He speculated that blood vessels too small to be seen by the human eye might explain how blood circulates. Four years after his death, an Italian physiologist, Marcello Malpighi, used a microscope to observe the tiniest blood vessels, the capillaries (from Latin, meaning "hairlike"). Malpighi's observations confirmed Harvey's theory of circulation. **Figure 2**, on the next page, shows the major blood vessels of the circulatory system, as they are known today.

DID YOU KNOW ?

Was Harvey First?
Evidence from an ancient Egyptian papyrus discovered in the 19th century suggests that the Egyptians correctly mapped the flow of blood from the heart 3300 years before William Harvey.

Arteries and Arterioles

artery a blood vessel that carries blood away from the heart

pulse change in the diameter of the arteries following heart contractions

Arteries are the blood vessels that carry blood away from the heart. They have thick walls composed of distinct layers. The outer and inner layers are primarily connective tissue, while the middle layers are made up of muscle fibres and elastic connective tissue, as shown in **Figure 3 (a)**, on page 314. Every time the heart contracts, blood surges from the heart and enters the arteries. The arteries stretch to accommodate the inrush of blood. The **pulse** you can feel near your wrist and on either side of your neck is created by changes in the diameter of the arteries following heart contractions. Heart contraction is followed by a relaxation phase. During this phase, pressure drops and elastic fibres in the walls of the artery recoil. It is interesting to note that the many cells of the artery are themselves supplied with blood vessels that provide nourishment. Blood from the arteries passes into smaller arteries, called arterioles. The middle layer of arterioles is composed of elastic fibres and smooth muscle.

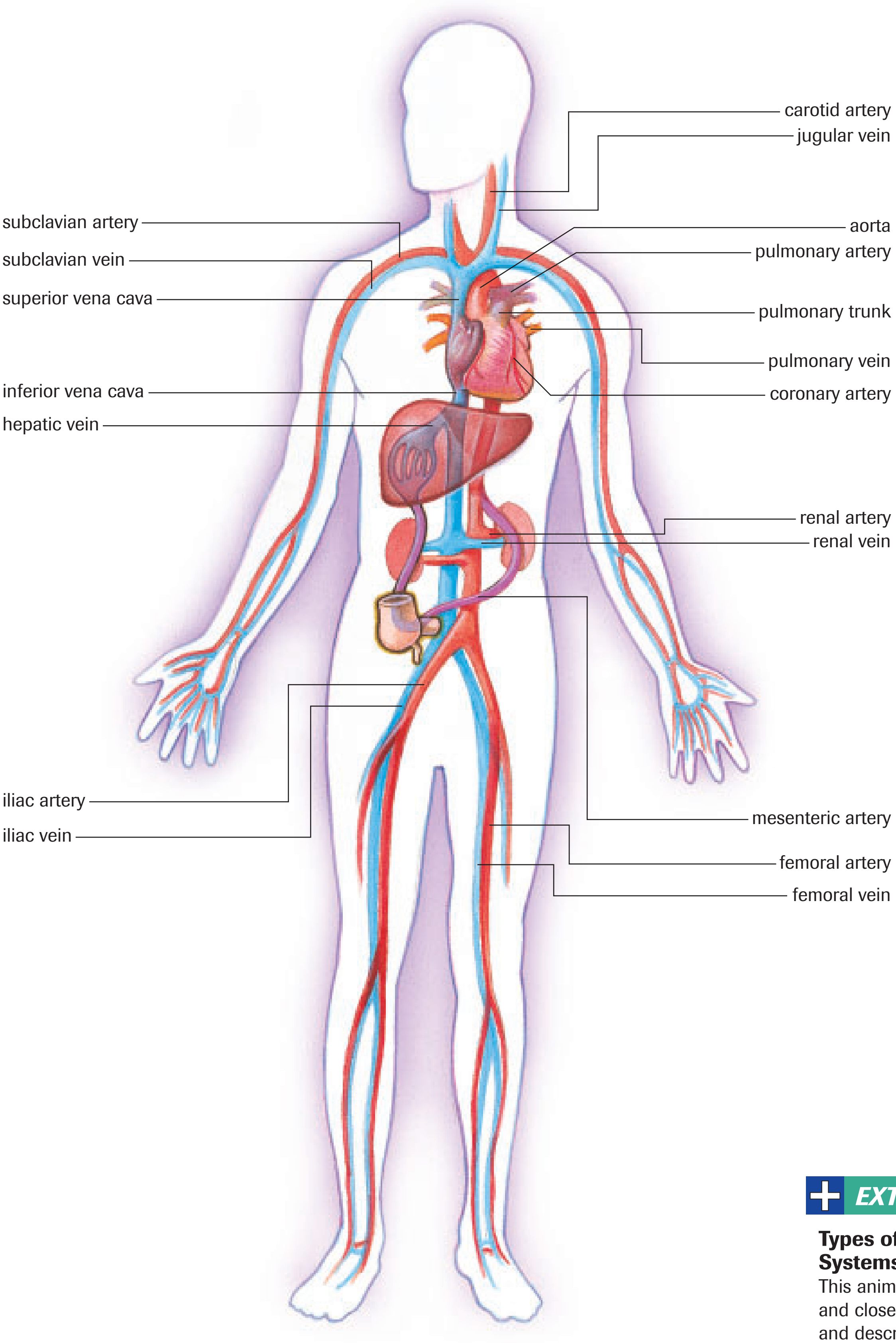


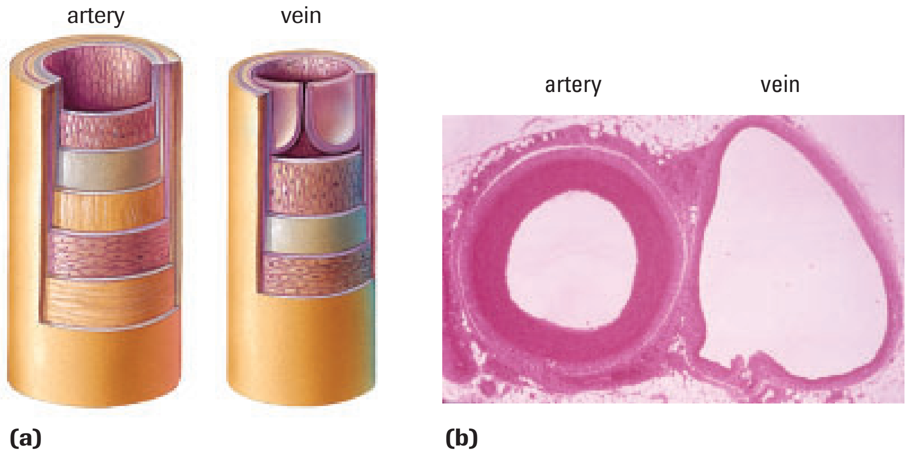
Figure 2
The major blood vessels of the circulatory system

EXTENSION

Types of Circulatory Systems
This animation compares open and closed circulatory systems and describes how each works.

www.science.nelson.com GO

Figure 3
(a) Arteries have strong walls capable of withstanding great pressure. The middle layer of arteries contains both muscle tissue and elastic connective tissue. The low-pressure veins have a thinner middle layer.
(b) The photo shows a cross section of an artery and a vein.



autonomic nervous system the part of the nervous system that controls the motor nerves that regulate equilibrium, and that is not under conscious control

vasoconstriction the narrowing of blood vessels, allowing less blood to the tissues

vasodilation the widening of blood vessels, allowing more blood to the tissues

The **autonomic nervous system**, which controls the motor nerves that maintain equilibrium, regulates the diameter of the arterioles. A nerve impulse causes smooth muscle in the arterioles to contract, reducing the diameter of the blood vessel. This process is called **vasoconstriction**. Vasoconstriction decreases blood flow to tissues. Relaxation of the smooth muscle causes dilation of the arterioles, and blood flow increases. This process, called **vasodilation**, increases the delivery of blood to tissues. This, in turn, permits the cells in that localized area to perform energy-consuming tasks.

Precapillary sphincter muscles regulate the movement of blood from the arterioles into capillaries. Blushing is caused by vasodilation of the arterioles leading to skin capillaries. Red blood cells close to the surface of the skin produce the pink colour. Vasodilation helps the body release some excess heat that is produced when you become nervous. Have you ever noticed someone's face turn a paler shade when they are frightened? The constriction of the arteriolar muscles diverts blood away from the outer capillaries of the skin toward the muscles. The increased blood flow to the muscles provides more oxygen and glucose to meet the energy demands of a response to a threat or danger.

Arterioles leading to capillaries open only when cells in that area require blood. It has been estimated that the body would need 200 L of blood if all the arterioles were open at one time. Although the majority of brain capillaries remain open, as few as one fiftieth of the capillaries in resting muscle remain open.

EXTENSION

Atherosclerosis and the Positive Feedback Cycle
Listen to this Audio Clip to understand the accelerating influence that positive feedback has on the development of atherosclerotic plaque and coronary artery disease.

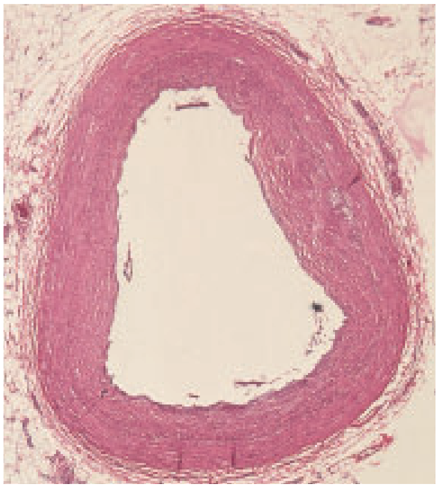
www.science.nelson.com GO

Atherosclerosis

Anyone who has ever washed dishes is aware of how fat floats on water. You may have noticed that when one fat droplet meets another, they stick together and form a larger droplet. Unfortunately, the same thing can happen in your arteries. Excess lipid in your blood is deposited in the walls of the arteries, slowly narrowing the inside diameter of the blood vessel. Calcium and other minerals deposit on top of the lipid, forming plaque. This condition is known as **atherosclerosis**, the most common form of a group of disorders called **arteriosclerosis,** or arterial disease. Arteriosclerosis can narrow arteries and lead to high blood pressure (**Figure 4**, next page). To make matters worse, blood clots, which are normally a life-saving property of blood, form in the blood vessel when the plaque gets so big that it bursts through the wall of the artery. This can totally block the artery and cut off blood flow. In the heart, as the arteries become narrowed and blocked, inadequate amounts of blood and oxygen are delivered to the heart muscle, resulting in chest pains and possibly a heart attack.

atherosclerosis a degeneration of blood vessels caused by the accumulation of fat deposits in the inner wall

arteriosclerosis a group of disorders that cause the blood vessels to thicken, harden, and lose their elasticity



(a)

(b)

Figure 4
(a) Cross section of a normal artery
(b) Cross section of an artery from a person with atherosclerosis. Notice that fat deposits have narrowed the passageway.

Every year heart disease kills more Canadians than any other disease. Lifestyle changes must accompany any medical treatment. A low-fat diet plus regular exercise are keys to prevention.

Aneurysm

An **aneurysm** is a bulge that forms in the wall of a weakened blood vessel, usually an artery. The most common sites are the aorta of the heart, the abdominal aorta, and arteries in the brain. Aneurysms are often due to atherosclerosis. In much the same way as the weakened wall of an inner tube begins to bulge, the weakened segment of the artery protrudes as blood pulses through. The thinner wall offers less support and eventually ruptures. Less oxygen and nutrients are delivered to the tissues, resulting in cell death. An aneurysm in the brain is one of the conditions that can cause a stroke.

aneurysm a bulge in the weakened wall of a blood vessel, usually an artery

mini *Investigation* — *Monitoring Your Pulse*

Walking or mild exercise will increase your heart rate by 20 % to 30 %. For those in good health, increased energy demands during extreme exercise can raise the heart rate to an incredible 200 beats per minute. Although few individuals can sustain such a rapid heart rate, it indicates the capacity of the heart to adjust to changing situations.

Do not perform this activity if you are not allowed to participate in physical education classes.

- While sitting still, place your index and middle finger near your wrist, as shown in **Figure 5**. The pulse you feel is blood rushing through the brachial artery in your arm. Count the number of heartbeats in 30 s. Record your pulse at rest and then calculate the heart rate as beats per min.
- Remain sitting quietly and place your index finger and middle finger on the side of your neck just to the side your trachea. You will feel blood pulse through the carotid artery, which is an artery that carries blood to the head. Take your pulse for 30 s and then calculate the heart rate for 1 min.
- Run on the spot for approximately 2 min.
- Take your pulse immediately after exercise using either the carotid artery or the brachial artery. Record your heart rate.

(a) Compare the strength of the pulse in the carotid artery with that in your arm.
(b) Compare your heart rate before and after exercise.
(c) Do you think the difference between resting heart rate and the heart rate after exercise would be greater for athletes? Explain your answer.

Figure 5
Arteries near the surface permit taking of the pulse.

Capillaries

Figure 6
Red blood cells in a capillary. Notice that the capillary is only wide enough for cells to pass through one at a time.

Capillaries, composed of a single layer of cells, are the sites of fluid and gas exchange between blood and body cells. Many active cells, such as muscle cells, may be supplied by more than one capillary. Most capillaries are between 0.4 and 1.0 mm long with a diameter of less than 0.005 mm. The diameter is so small that red blood cells must travel through capillaries in single file (**Figure 6**). The single cell layer of capillaries, although ideal for diffusion, creates problems. Capillary beds are easily destroyed. High blood pressure or any impact, such as that caused by a punch, can rupture the thin-layered capillary. Bruising occurs when blood rushes into the spaces between tissues.

Oxygen diffuses from the blood into the surrounding tissues through the thin walls of the capillaries into the body cells. Oxygenated (oxygen-rich) blood appears red in colour, while deoxygenated (oxygen-poor) blood appears purple-blue as it leaves the capillary. The deoxygenated blood collects in small veins called venules and is carried back to the heart. Some protein is also exchanged, but this process is not believed to involve diffusion. Water-soluble ions and vitamins are believed to pass through spaces in the walls of the capillary vessels. Because some spaces are wider than others, some capillaries may be more permeable than others.

mini *Investigation* — *Observing Blood Flow in a Fish Tail*

William Harvey described the movement of blood through vessels in the early 1600s. He concluded that blood carried nutrients to tissues and transported wastes away from tissues to specialized organs. Unable to see capillaries, Harvey speculated that tiny blood vessels were the sites of diffusion of wastes and nutrients between cells and the circulating blood.

Materials: goldfish, net, absorbent cotton, Petri dish, cover slip, light microscope

- Using the net, carefully remove a small goldfish from the aquarium and place it in the Petri dish.
- Cover the goldfish, except the head and tail, with absorbent cotton that has been soaked with aquarium water. Place enough cotton to completely cover the fish. The gills must be covered and soaked with water.
- Add a cover slip to the tail (**Figure 7**).
- Position the Petri dish on the stage of a light microscope and observe the fish tail under low-power magnification.
- When you have completed your observations, gently remove the cotton and submerge the Petri dish into the aquarium to release the fish unharmed.

(a) Describe the movement of blood in arterioles, capillaries, and venules.

(b) Explain why capillary walls are much thinner than those of the arterioles or venules.

(c) Blood cells squeeze through capillaries, moving in single file. Explain the advantage of single-file motion and the slowing of blood cells through the capillary.

(d) Where would you expect to find more capillaries: muscle tissue or fat tissue? Give reasons for your answer.

(e) Live animals are used in many research experiments. Comment of the use of live animals in research.

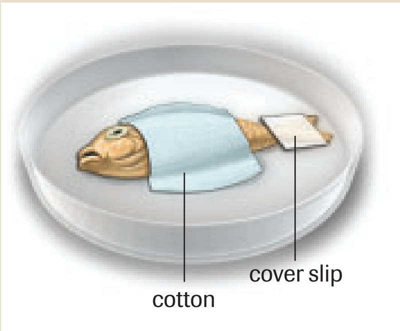


Figure 7
Experimental setup

Practice

1. What causes a pulse?
2. Define vasodilation and vasoconstriction.
3. What are the functions of capillaries?

Veins and Venules

Capillaries merge and become progressively larger vessels, called venules. Unlike capillaries, the walls of venules contain smooth muscle. Venules merge into **veins**, which have greater diameter. Gradually, the diameter of the veins increases as they approach the heart. However, the process of returning the blood to the heart is difficult. As blood flows from arteries to arterioles to capillaries, blood flow is greatly reduced. As blood passes through a greater number of narrower vessels with weaker walls, fluid pressure is reduced. (See **Figure 3** on page 314 for a comparison of the walls of arteries and veins.) By the time blood enters the venules, the pressure is between 15 mmHg and 20 mmHg. This pressure is not enough to drive the blood back to the heart, especially from the lower limbs.

vein a blood vessel that carries blood toward the heart

How then does blood get back to the heart? William Harvey, the English physiologist, conducted experiments to answer that question. In one experiment, he tied a band around the arm of one of his subjects, restricting venous blood flow. The veins soon became engorged with blood and swelled. Harvey then placed his finger on the vein and pushed blood toward the heart. The vein closed up or collapsed. Harvey repeated the procedure, but this time he pushed the blood back toward the hand. Bulges appeared in the vein at regular intervals. What caused the bulges? Dissection of the veins confirmed the existence of valves.

The valves open in one direction, steering blood toward the heart. They do not allow blood to flow back in the other direction (**Figure 8 (a)**). When Harvey tried to push blood toward the hand, the valves closed, causing blood to pool in front of the valves and distend the vein. When he directed blood toward the heart, the valves opened and blood flowed from one compartment into the next. The vein collapsed because the band tied around the arm prevented the blood from passing.

Skeletal muscles also aid venous blood flow. Venous pressure increases when skeletal muscles contract and push against the vein. The muscles bulge when they contract, thereby reducing the vein's diameter. Pressure inside the vein increases and the valves open, allowing blood to flow toward the heart. Sequential contractions of skeletal muscle create a massaging action that moves blood back to the heart (**Figure 8 (b)**). This may explain why you feel like stretching first thing in the morning. It also provides a reason why some people faint after standing still for long periods of time. Blood begins to pool in the lower limbs and cannot move back to the heart without movement of the leg muscles.

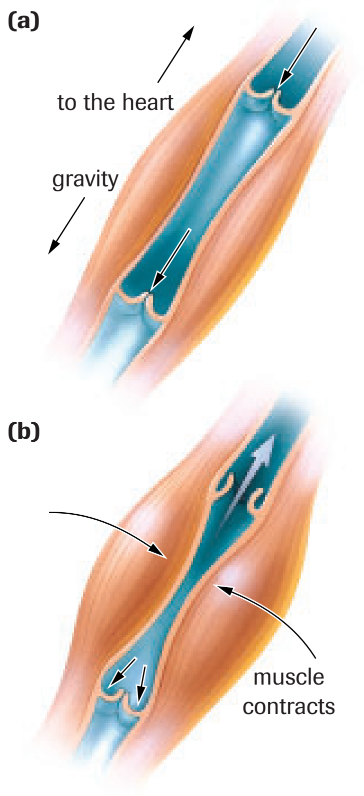


Figure 8
Venous valves and skeletal muscle work together in a low-pressure system to move blood back to the heart.

The veins serve as more than just low-pressure transport canals; they are also important blood reservoirs. As much as 65 % of your total blood volume can be found in the veins. During times of stress, venous blood flow can be increased to help you meet increased energy demands. Nerve impulses cause smooth muscle in the walls of the veins to contract, increasing fluid pressure. Increased pressure drives more blood to the heart.

Unfortunately, veins, like other blood vessels, are subject to problems. Large volumes of blood can distend the veins. In most cases, veins return to normal diameter, but if the pooling of blood occurs over a long period of time, the one-way valves are damaged. Without proper functioning of the valves, gravity carries blood toward the feet and greater pooling occurs. Surface veins gradually become larger and begin to bulge. This disorder is known as varicose veins. Although there is a genetic link to weakness in the vein walls, lifestyle can accelerate the damage. Prolonged standing, especially with restricted movement, increases pooling of blood. Prolonged compression of the superficial veins in the leg can also contribute to varicose veins.

mini Investigation — Mapping Veins

CAUTION: Do not leave the sphygmomanometer inflated past 30 mmHg or on longer than 5 min.

- Place a pressure cuff (sphygmomanometer) over a subject's upper arm and inflate it to 30 mmHg.
- Locate one of the veins on the inside of the subject's arm and use your index finger to push blood in the vein toward the elbow.
- Describe the appearance of the vein. Draw a diagram to illustrate your description.
- Now push the blood in the vein toward the fingers.
- Describe the appearance of the vein. Draw a diagram to illustrate your description.

(a) How do you know that the blood vessel is a vein and not an artery?

SUMMARY — Blood Vessels

- Arteries carry blood away from the heart.
- Vasoconstriction is a reduction in the diameter of the blood vessel, decreasing blood flow and the amount of oxygen to the tissues. Vasodilation is an increase in the diameter of the blood vessel, increasing blood flow and the amount of oxygen to the tissues.
- Atherosclerosis is a narrowing of the arteries due to a buildup of plaque that contains fat.
- Capillaries are the site of fluid and gas exchange between the blood and the cells.
- Veins carry blood toward the heart.
  - Pressure in the veins is much lower than in the arteries.
  - One-way valves and skeletal muscles help venous blood flow.

Section 10.1 Questions

1. Explain what happens in the blood vessels when someone blushes. Why does this happen?
2. Are all the capillaries open all the time? Why or why not? What determines whether a capillary is open?
3. What are the advantages and disadvantages of capillaries being composed of a single cell layer?
4. Explain the importance of William Harvey's theory of blood circulation.
5. Why are aneurysms dangerous?
6. Prepare a table comparing arteries and veins.
7. Fluid pressure is very low in the veins. Explain how blood gets back to the heart.
8. What causes varicose veins? What lifestyle changes could prevent the development of varicose veins?
9. Atherosclerosis is a disease caused by the buildup of plaque inside an artery.
   (a) Explain how it occurs.
   (b) What problems can be created by the buildup of plaque?
   (c) Suggest a treatment for the disorder.

The Heart 10.2

The heart is a muscular organ that pumps to circulate blood throughout the body. A fluid-filled membrane called the pericardium surrounds the heart. The fluid bathes the heart, preventing friction between its outer wall and the covering membrane.

The heart consists of two parallel pumps separated by the **septum**. The pumping action is synchronized; muscle contractions on the right side mirror those on the left. The pump on the right receives deoxygenated blood from the body tissues and pumps it to the lungs. The pump on the left receives oxygenated blood from the lungs and pumps it to the cells of the body. Vessels that carry blood to and from the lungs make up the **pulmonary circulatory system**. Vessels that carry blood to and from the body make up the **systemic circulatory system**. **Figure 1** illustrates the two systems.

The four-chambered human heart is composed of two thin-walled **atria** (singular: **atrium**) and two thick-walled **ventricles**. Blood from the systemic system enters the right atrium, and blood from the pulmonary system enters the left atrium. The stronger, more muscular ventricles pump the blood to distant tissues.

septum a wall of muscle that separates the right and left sides of the heart

pulmonary circulatory system the system of blood vessels that carries deoxygenated blood to the lungs and oxygenated blood back to the heart

systemic circulatory system the system of blood vessels that carries oxygenated blood to the tissues of the body and deoxygenated blood back to the heart

atrium (plural: **atria**) a thin-walled chamber of the heart that receives blood from veins

ventricle a muscular, thick-walled chamber of the heart that delivers blood to the arteries

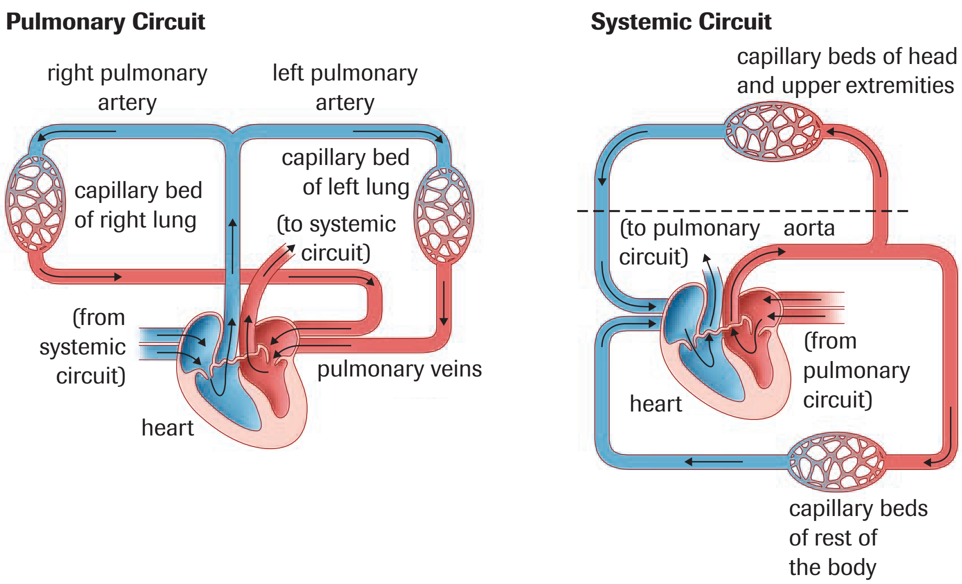


Figure 1
The pulmonary and systemic circuits of the circulatory system. The blood vessels carrying oxygenated blood are in red; the vessels carrying deoxygenated blood are in blue.

One-Way Blood Flow

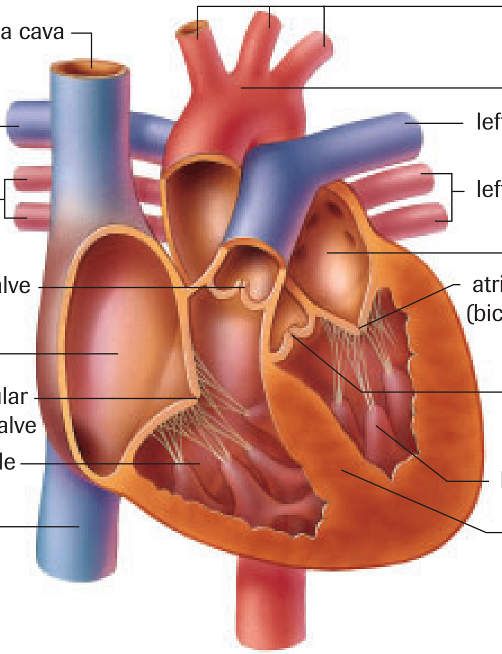
Blood is carried to the heart by veins. The superior vena cava carries deoxygenated blood from the head and upper body to the right atrium. The inferior vena cava carries deoxygenated blood from all veins below the diaphragm to the same atrium. Oxygenated blood flowing from the lungs enters the left atrium by way of the pulmonary veins. Blood from both atria is eventually pumped into the ventricles.

Valves called **atrioventricular (AV) valves** separate the atria from the ventricles. In much the same way as the valves within veins ensure one-directional flow, the AV valves prevent the flow of blood from the ventricles back into the atria. The AV valves are supported by bands of connective tissue called chordae tendinae. A second set of valves, called **semilunar valves**, separate the ventricles from the arteries. These valves are half-moon shaped (hence, the name *semilunar*), and they prevent blood that has entered the arteries from flowing back into the ventricles (**Figure 2**, next page).

atrioventricular (AV) valve a heart valve that prevents the backflow of blood from a ventricle into an atrium

semilunar valve a valve that prevents the backflow of blood from an artery into a ventricle

Figure 2
Anatomy of the human heart



aorta the largest artery in the body; carries oxygenated blood to the tissues

coronary artery an artery that supplies the cardiac muscle with oxygen and nutrients

Blood is carried away from the heart by arteries. The **aorta**, the largest artery in your body, carries oxygenated blood away from the heart. The **coronary arteries**, arteries that form an important branch of the aorta, supply the muscle cells of the heart with oxygen and nutrients. A blocked artery illustrates the importance of proper coronary circulation. Chest pain, or angina, occurs when too little oxygen reaches the heart. The heart, unlike other organs that slow down if they cannot receive enough nutrients, must continue beating no matter what demands are placed on it. It has been estimated that the heart may use 20 % of the body's total blood oxygen during times of stress.

As with other arteries, fat deposits and plaque can collect inside coronary arteries. Medications are often used to increase blood flow, but in severe situations blood flow must be rerouted. A coronary bypass operation involves removing a vein from another part of the patient's body and grafting it into the heart (**Figure 3**). However, for the vein to be grafted, the heart must be temporarily stopped. During the operation, the patient's heart is cooled and a heart–lung machine is used to supply oxygen and push blood to the tissues of the body.

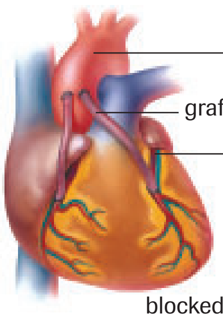


Figure 3
Coronary bypass operation. Blood flow is rerouted around the blockage.

Practice

1. Differentiate between the systemic and the pulmonary circulatory systems.
2. What is the function of the AV valves and the semilunar valves?
3. What is angina and what causes it?
4. What is a coronary bypass operation and why is it performed?

EXPLORE an issue

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Growing a New Heart

Cardiovascular disease is the leading cause of death in North America. About 44 000 Canadians, 40 % of them younger than 65 years, die each year from heart disease. Over 4000 patients in Canada and the United States are on the waiting list for a new heart. Only the sickest patients make the list, and not all of them will receive a new heart—some will die waiting. Aggressive campaigns to educate people about the importance of organ donation have resulted in increased numbers of donors. However, it may not be enough. Over the past few years, the demand for organs has been rising by about 15 % per year, and this rate will likely increase. Fewer than 3000 patients worldwide receive heart transplants annually.

Dr. Michael Sefton (**Figure 4**), director of the Institute of Biomaterials and Biomedical Engineering at the University of Toronto, has a solution that would provide an almost unlimited number of hearts for transplant. What Sefton calls a "heart in a box" is a transplantable heart that can be grown in the laboratory.

First, researchers must create scaffolding that the cells will grow around (**Table 1**). Typically, biodegradable plastics are used. The next step is to seed the scaffolding with living cells. The scaffolding and cells are then placed in a bioreactor—a sort of incubator that maintains constant temperature and provides the nutrients and oxygen required to support cell division. The cells secrete proteins and growth factors that bind them together to form living tissues. Although researchers have not yet been able to grow a complete living heart, they have successfully grown components of the heart.

Statement

Individuals who adopt unhealthy lifestyle choices that are dangerous to the health of their heart should not have the opportunity to have another one grown for them.

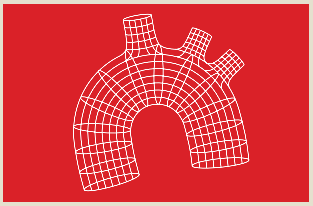
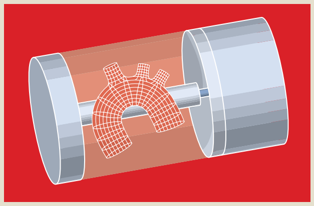
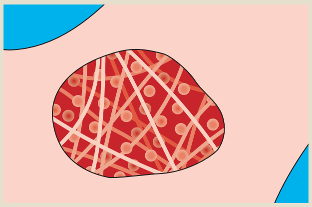
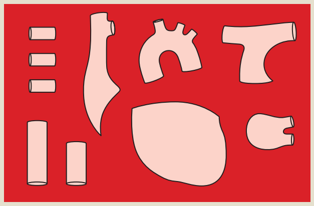
Figure 4
Dr. Michael Sefton

1. Form a group and research the issue.

   www.science.nelson.com GO

2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statement.
5. Defend your position in the debate.
6. Should this technology be used to support people who have an unhealthy lifestyle?

Table 1 Procedure for Growing a Heart

1. Cells are placed on plastic scaffolding.		2. The scaffolding, seeded with cells, is placed in a bioreactor that provides nutrients and oxygen.	
3. The cells divide and fill the open spaces of the scaffolding.		4. This technique can be used to grow parts of the heart and perhaps, eventually, the entire organ.	

INVESTIGATION 10.1 *Introduction*

Fetal Pig Dissection

The organ systems of humans and pigs are arranged in the body in very similar ways. In this investigation, you will explore the arrangement of the digestive, respiratory, and circulatory systems that you have learned about in this unit.

To perform this investigation, turn to page 340.

Report Checklist

- ● Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

WEB Activity

Simulation—Observing the Movement of Blood through the Heart

In this activity, you will follow the movement of blood through a virtual beating heart. Before you begin, write or draw a description of how you think blood moves through the heart. After you have finished, make any changes that are needed.

www.science.nelson.com GO

Cardiac Catheterization

At one time, doctors had to rely on external symptoms to detect coronary artery blockage. An inability to sustain physical activity, rapid breathing, and a general lack of energy are three of the symptoms of coronary distress. However, these same symptoms can also indicate a wide variety of other circulatory and respiratory diseases. One way to determine whether or not a patient is suffering from coronary artery problems is to perform surgery. Unfortunately, the surgery is not without risks. Clearly, less invasive means for diagnosing the problem would be desirable.

One of the most useful techniques to detect coronary artery blockage is cardiac catheterization. In this procedure, a small, thin hollow tube, called a catheter, is passed into an artery in the groin as the patient lies on an examination table. The catheter is then pushed up through the aorta and into the heart. A dye visible on X-ray film is then injected into the catheter. The dye travels through the blood vessels while its image is traced by a fluoroscope (a fluorescent screen). The image can also be projected on a television monitor (**Figure 5**). An area of restricted blood flow pinpoints the region of blockage. The catheter helps direct the surgeon to the problem prior to surgery. In a technique known as angioplasty, the catheter has a tiny balloon attached that can be inflated to open up the blocked blood vessel.

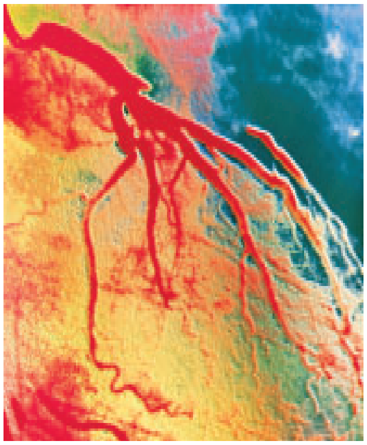


Figure 5
Dye showing the coronary arteries

Blood samples can also be taken with the catheter to determine how much oxygen is in the blood in the different chambers. This tells the physician how well the blood is being oxygenated in the lungs. Low levels of oxygen in the left side of the heart can provide information about whether the circulatory and respiratory systems are working together efficiently. The catheter can even be used to monitor pressures in each of the heart chambers.

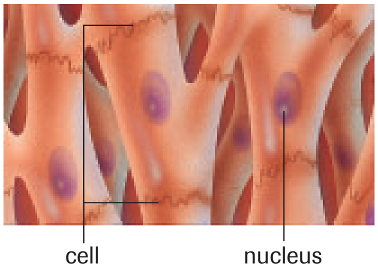


Figure 6
The heart is composed of cardiac muscle, which has a unique branching pattern.

Setting the Heart's Tempo

Heart, or cardiac, muscle differs from other types of muscle. Like skeletal muscle, cardiac muscle appears striated (striped) when viewed under a microscope. But unlike skeletal muscle, cardiac muscle displays a branching pattern (**Figure 6**). The greatest difference stems from the ability of this muscle to contract without being stimulated by external nerves. Muscle with this ability, called **myogenic muscle**, explains why the heart will continue to beat, at least for a short time, when removed from the body.

myogenic muscle muscle that contracts without external nerve stimulation

The remarkable capacity of the heart to beat can be illustrated by a simple experiment. When a frog's heart is removed and sliced into small pieces while in a salt solution that simulates the minerals found within the body, each of the pieces continues to beat, although not at the same speed. Muscle tissue from the ventricles follows a slower rhythm than muscle tissue from the atria. Muscle tissue closest to where the venae cavae enter the heart has the fastest tempo. The unique nature of the heart becomes evident when two separated pieces are brought together. The united fragments assume a single beat. The slower muscle tissue assumes the tempo set by the muscle tissue that beats more rapidly.

The heart's tempo or beat rate is set by the **sinoatrial (SA) node** (**Figure 7**). This bundle of specialized nerves and muscles is located in the upper right atrium. The SA node acts as a pacemaker, setting a rhythm of about 70 beats per minute for the heart. Nerve impulses are carried from the pacemaker to other muscle cells by modified muscle tissue. Originating in the atria, the contractions travel to a second node, the **atrioventricular (AV) node**. The AV node serves as a conductor, passing nerve impulses via two large nerve fibres, called **Purkinje fibres**, through the septum toward the ventricles. The Purkinje fibres run along the septum that separates the right and left ventricles, carrying impulses from the AV node to the bottom tip of the heart. From here, these branching fibres carry impulses up along the outer walls of the ventricles back toward the atria. A wave of cardiac contraction follows the nerve pathway. Both the right and left atria contract prior to the right and left ventricles. One of the greatest challenges for surgeons performing open-heart surgery is to make incisions at the appropriate location. A scalpel placed in the wrong spot could cut fibres that conduct nerve impulses.

Heart rate is influenced by autonomic nerves. Two regulatory nervous systems—the **sympathetic** and **parasympathetic nervous systems**—conduct impulses from the brain to the SA node. Stimulated during times of stress, the sympathetic nerves increase heart rate. This increases blood flow to tissues, enabling the body to meet increased energy demands. When the heart rate exceeds 100 beats per min, this is referred to as tachycardia. Tachycardia can result from exercise or from the consumption of such drugs as caffeine or nicotine. During times of relaxation, the parasympathetic nerves are stimulated to slow the heart rate.

sinoatrial (SA) node a small mass of tissue in the right atrium that originates the impulses stimulating the heartbeat

atrioventricular (AV) node a small mass of tissue in the right atrioventricular region through which impulses from the sinoatrial node are passed to the ventricles

Purkinje fibre a nerve fibre that branches and carries electrical impulses throughout the ventricles

sympathetic nervous system a division of the autonomic nervous system that prepares the body for stress

parasympathetic nervous system a division of the autonomic nervous system that returns the body to normal resting levels following adjustments to stress

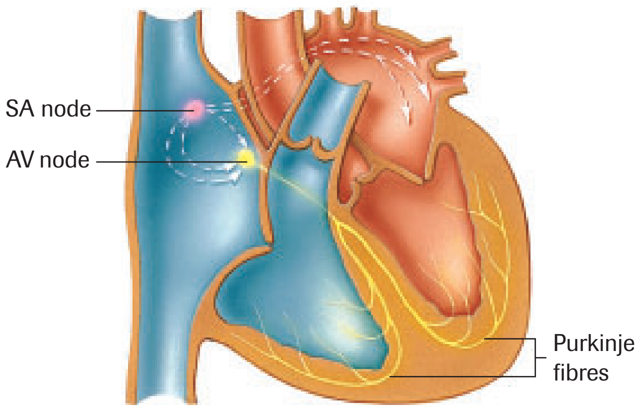


Figure 7
The SA node initiates heart contractions. Modified muscle tissue passes a nerve impulse from the pacemaker down the dividing septum toward the ventricles.

Practice

5. What is myogenic muscle?

6. What is the difference between the sympathetic and the parasympathetic nervous systems?

Case Study

Diagnosing Heart Conditions

Physicians can use electrocardiographs, which map electrical fields within the heart, to make tracings to diagnose certain heart problems. Electrodes that can detect the electrical impulses of the heart are placed on the body surface are connected to a recording device. The electrical impulses are displayed on a graph called an electrocardiogram (ECG) (**Figure 8**). Changes in electrical current reveal normal or abnormal events of the cardiac cycle. The first wave, referred to as the P wave, represents the electrical impulse that causes atrial contraction. The larger spike, referred to as the QRS wave, represents the electrical impulse that causes ventricular contraction. A final T wave signals that the ventricles have recovered. A patch of dead heart tissue, for example, will not conduct impulses and produces abnormal line tracings (**Figure 9**). By comparing the tracings, physicians are able to locate the area of the heart that is damaged.

The electrocardiograph is especially useful for monitoring the body's response to exercise. Stress tests are performed by monitoring a subject who is riding a stationary bike or running on a treadmill. Some heart malfunctions remain hidden during rest, but can be detected during vigorous exercise.

Physicians often refer to an irregular heartbeat as arrhythmia (**Figure 10**). One cause of arrhythmia is a blocked coronary artery. When a coronary artery is blocked, it delivers less blood and can cause the heart to beat in an irregular pattern. The buildup of toxic products associated with poor oxygen delivery can initiate contractions of the heart muscle. Rather than synchronized heartbeats, where muscle cells within the ventricles pick up electrical signals from surrounding muscle fibres, each cell within the ventricle responds to the toxins surrounding it and begins to contract wildly. This is referred to as ventricular fibrillation.

As the heart fibrillates, blood is not pumped in a coordinated fashion. The twitching heart pushes blood back and forth, reducing its ability to deliver needed oxygen. The heart responds by beating faster, but without a controlled pattern of muscle contraction, blood delivery to the tissues will not improve.

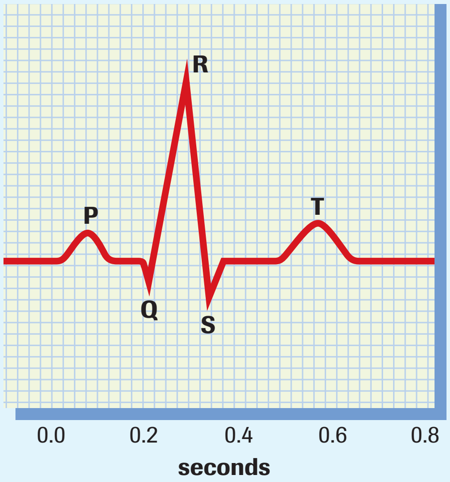


Figure 8
Electrocardiogram (ECG) showing the duration of a single beat. The flat lines show the resting period between beats.

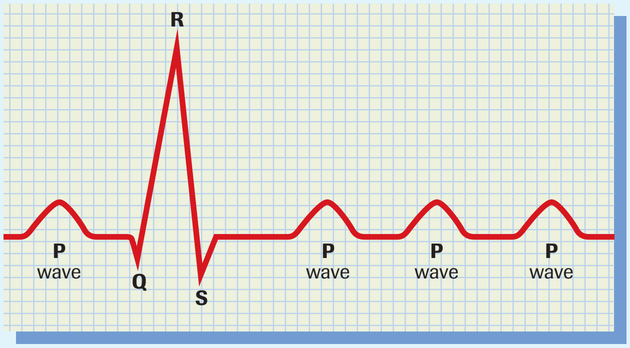


Figure 9
An abnormal electrocardiogram

Case Study Questions

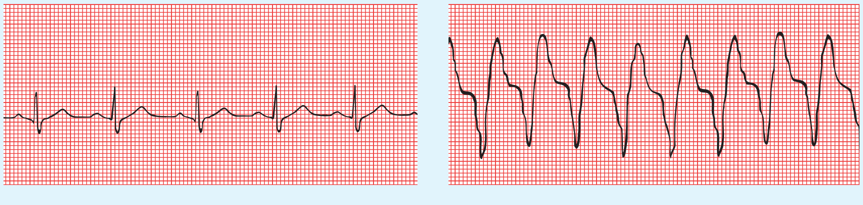
1. What do the repetitive P waves in **Figure 9** indicate?

2. What would a small QRS wave indicate?

3. What is arrythmia?

4. Why is ventricular fibrillation dangerous?

Figure 10
Not all arrhythmias are abnormal. The ECG in **(a)** is a slowed heart rate associated with athletes. The ECG in **(b)** shows an uncontrolled heart rate, or ventricular fibrillation.



(a) **(b)**

Heart Sounds

The familiar *lubb-dubb* heart sounds are caused by the closing of the heart valves. The period of relaxation of the heart is called diastole, during which both the atria and the ventricles are relaxed. When the atria are relaxed, they fill with blood (**Figure 11 (a)**). The atria then contract, increasing fluid pressure and forcing the AV valves open. Blood flows from the atria into the ventricles (**Figure 11 (b)**). In turn, the filled ventricles contract. The pressure forces the AV valves shut, producing a heavy *lubb* sound and pushing blood through the semilunar valves and into the arteries (**Figure 11 (a)**). The period of contraction is called **systole**. The ventricles then relax, and their volume increases. With increased volume, pressure in the ventricles decreases and blood tends to be drawn from the arteries toward the area of lower pressure; however, the blood is prevented from re-entering the ventricles by the semilunar valves. The closing of the semilunar valves creates the lighter *dubb* sound.

diastole relaxation (dilation) of the heart, during which the atria fill with blood

systole contraction of the heart, during which blood is pushed out of the heart

Occasionally, the valves do not close completely. This condition is one cause of heart murmurs. The heart murmur occurs when blood leaks past the closed heart valve because of an improper seal. The AV valves, especially the left AV valve (the bicuspid valve), are especially susceptible to defects. The rush of blood from the ventricle back into the atrium produces a gurgling sound that can be detected with a stethoscope. Blood flowing back toward the atrium is inefficient because it is not directed to the systemic or pulmonary systems. The hearts of individuals who experience these murmurs compensate for decreased oxygen delivery by beating faster and eventually enlarging.

A second mechanism helps compensate for decreased blood flow in people with leaky heart valves. Like an elastic band, the more cardiac muscle is stretched, the stronger is the force of contraction. When blood flows from the ventricle back into the atrium, blood volume in the atrium increases. The atrium accepts the normal volume and the additional blood from the ventricle. The extra volume stretches the atrium and drives blood to the ventricle with greater force. The increased blood volume in the ventricle causes it to contract with greater force, driving more blood to the tissues.

DID YOU KNOW?

The First Stethoscope

In 1816, René Laennec, a young physician, was examining a patient for heart distress. The practice at the time was for the doctor to place his ear on the patient's chest and listen for the *lubb-dubb* sounds. However, Laennec decided to try another approach. He rolled up a paper and placed it to the patient's chest. The heart sounds became clearer. Later, wooden cylinders were used, eventually to be replaced by the modern Y-shaped stethoscope.

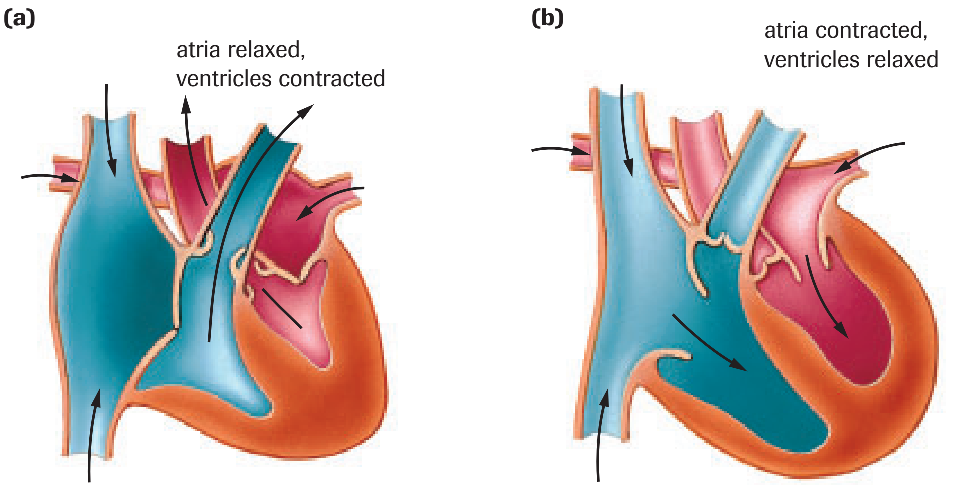


Figure 11
(a) The relaxed atria fill with blood. Ventricular contractions close the AV valves and open the semilunar valves.
(b) The relaxation of the ventricles lowers pressure and the right and left atria contract in unison, pushing blood into the right and left ventricles. The closing of the semilunar valves prevents blood from re-entering the ventricles.

Practice

7. Explain the terms *diastole* and *systole.*
8. What causes the characteristic heart sounds?
9. What is one cause of heart murmurs?

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

The State of Statins

Researchers interviewed in this clip support the use of a class of drugs called statins to treat individuals with high cholesterol, to reduce the risk of heart disease. However, using drugs on otherwise healthy people, particularly before they change their eating and exercise habits, is controversial.

www.science.nelson.com GO

Medications and the Heart

Many traditional homeopathic medical treatments are now being supported by science. Foxglove *(Digitalis purpurea)*, a popular garden plant in Britain, has long been used in tea as a tonic. Scientists have found that the active ingredient in the plant, digitalis, initiates strong, regular heart contractions, and it is now used to treat congestive heart failure. Nitroglycerin, an explosive, has also been used to prevent heart attacks. It works by relaxing smooth muscle and dilating blood vessels.

Medical therapy for heart failure has improved greatly with the development of beta-blockers. These drugs are especially important for people with irregular heartbeats or who display the effects of high blood pressure.

Receptor sites located on the surface of cells receive molecules, such as hormones, that affect the way cells behave. Epinephrine, a stress hormone, attaches to receptors on the heart and blood vessels, increasing heart rate and narrowing the blood vessels. Both effects lead to an increase in blood pressure. Beta-blockers tie up receptor sites that accept epinephrine.

There are two types of beta-receptors on cell surfaces, beta 1 and beta 2. Beta 1 receptors are found on the surface of the cardiac muscle. These affect the speed and strength of heart contractions and directly influence blood pressure. Beta 2 receptors are found primarily in the blood vessels and the bronchioles leading into the lungs. When the effects of the stress hormone are blocked, the heart rate slows and blood vessels relax, leading to a reduction in blood pressure.

Like most medications, beta-blockers can have side effects. Since they reduce the effects of stress hormones by slowing the heart, patients may feel tired, be less able to exercise vigorously, or experience lightheadedness or dizziness due to low blood pressure.

mini Investigation — Effects of Caffeine on Heart Rate

Materials: concave depression slide, glycerin, cover slip, *Daphnia* culture, strong coffee (not hot), medicine dropper, pencil, paper, watch

- Place a few drops of glycerin into the depression slide.
- Using a medicine dropper, place a small drop of the *Daphnia* culture onto the glycerin.
- Prepare a wet mount by adding a cover slip and observe under low magnification.
- While observing the beating heart, have your lab partner indicate a start time and a stop time 30 s later. Mark with your pencil on a piece of paper every time the heart beats.
- Record the heart rate for *Daphnia.* Conduct two more trials.
- Remove the cover slip and add a drop of coffee. Replace the cover slip and repeat the same procedure.

(a) Record the data you have collected in a data table.
(b) Calculate the mean heart rate for the control and the caffeine.
(c) Present the data you have collected using a graph.
(d) How did caffeine affect heart rate?
(e) It was noted that two different groups did not have exactly the same data. Identify variables that could affect the heart rate.
(f) What changes would you suggest to produce repeatable data?

SUMMARY The Heart

- The pulmonary circulatory system is the system of blood vessels that carries blood to and from the lungs. The systemic circulatory system is the system of blood vessels that carries blood to and from the body.
- The heart consists of two parallel pumps separated by the septum.
  - Blood enters the heart through the atria.
  - Ventricles pump the blood to the body tissues.
  - Atrioventricular valves prevent the flow of blood from the ventricles back into the atria.
  - Semilunar valves prevent blood the flow of blood from arteries back into the ventricles.
  - Coronary arteries supply the heart with oxygen and nutrients.
- The heart rate is set by the sinoatrial (SA) node. Contractions in the SA node travel to the atrioventricular (AV) node and then travel along the Purkinje fibres to the rest of the heart.
- Diastole is heart relaxation. Systole is heart contraction.
- The *lubb-dubb* sound is caused by the AV valves and the semilunar valves closing in turn as blood is pushed from the atria through the ventricles and out of the heart. If the valves do not close completely, the heart compensates by beating faster and pumping blood with more force.

EXTENSION

Operation: Heart Transplant
Enter the virtual *NOVA* operating theatre, where you will be given a scalpel and perform a heart transplant.

www.science.nelson.com GO

Section 10.2 Questions

1. What are the atria and the ventricles? How do they differ in structure and function?
2. In what sense is blood flow in the body one way?
3. Draw and label the major blood vessels and chambers of the heart. Trace the flow of deoxygenated and oxygenated blood through the heart.
4. Describe cardiac catheterization and explain its usefulness.
5. Explain differences in the strength of a pulse between the carotid artery (neck area) and the brachial artery (wrist area).
6. Explain changes in the pulse after exercise.
7. Describe the pathway of nerve impulses through the heart. Refer to the terms *sinoatrial node, atrioventricular node,* and *Purkinje fibres.*
8. How does the heart compensate for the improper function of the AV valves?
9. What is an electrocardiogram? Why is it useful? Explain what the different waves of an electrocardiogram indicate.
10. Draw a flow chart or diagram to show how a beta-blocker works.
11. When researching the impact of scientific knowledge or technology on society, what kinds of sources do you consult? Do you think that medical or scientific sources will give an impartial point of view? Explain.
12. Medical technologies are often patented, bringing in great profits to the owners. Using print or electronic media, find out about some of these technologies. Do you think that technology such as an artificial heart should be owned? What are the social and moral implications of such ownership?

    www.science.nelson.com GO

13. Predict some advantages and disadvantages of artificial hearts over donor hearts.
14. All drugs that block beta 2 receptors also block beta 1 receptors. Some drugs work selectively by blocking beta 1 receptors without affecting the beta 2 receptors. Indicate which drug, a beta 2 nonselective or beta 1 selective drug, would produce fewer side effects. Give your reasons.

10.3 Regulation of Blood Flow

Blood surges through the arteries with every beat of the heart. Elastic connective tissue and smooth muscle in the walls of the arteries stretch to accommodate the increase in fluid pressure. The arterial walls recoil much like an elastic band as the heart begins the relaxation phase characterized by lower pressure. Even the recoil forces help push blood through arterioles toward the tissues.

Cardiac Output

Cardiac output is defined as the amount of blood that flows from the heart per minute. Unless some dysfunction occurs, the amount of blood pumped from the right side of the heart is equal to the amount of blood pumped from the left side of the heart. Two factors affect cardiac output: stroke volume and heart rate.

cardiac output the amount of blood pumped from the heart each minute

stroke volume the quantity of blood pumped with each beat of the heart

Stroke volume is the quantity of blood pumped with each beat of the heart. The stronger the heart contraction, the greater the stroke volume. Approximately 70 mL of blood per beat leave each ventricle while you are resting. *Heart rate* is the number of times the heart beats per minute. The equation below shows how cardiac output is determined using stroke volume and heart rate.

$$\begin{aligned} \text{cardiac output} &= \text{stroke volume} \times \text{heart rate} \\ &= 70\ \text{mL/beat} \times 70\ \text{beats/min} \\ \text{cardiac output} &= 4900\ \text{mL/min} \end{aligned}$$

Individuals who have a mass of 70 kg must pump approximately 5 L of blood per minute. Smaller individuals require less blood and, therefore, have lower cardiac outputs. Naturally, cardiac output must be adjusted to meet energy needs. During exercise, heart rate increases to meet increased energy demands.

The cardiac output equation provides a basis for comparing individual fitness. Why do two people with the same body mass have different heart rates? If you assume that both people are at rest, both should require the same quantity of oxygen each minute. For example, Tom, who has a heart rate of 100 beats per minute, has a lower stroke volume. Lee, who has a heart rate of 50 beats per minute, has a higher stroke volume.

DID YOU KNOW?

What's Your Resting Heart Rate?

Due to greater stroke volume, some athletes have much slower heart rates. The tennis player Bjorn Borg once demonstrated a resting heart rate of 35 beats/min.

Table 1 Cardiac Output of Two People

Person	Stroke volume (mL/beat)	Heart rate (beats/min)	Cardiac output (stroke volume × heart rate)
Tom	50	100	5 L
Lee	100	50	5 L

Lee's lower heart rate indicates a higher stroke volume. Strong hearts can pump greater volumes of blood with each beat. This is why athletes often have low heart rates. Hearts that are less strong are unable to pump as much blood per beat, but compensate by increasing heart rate to meet the body's energy demands. It is important to recognize that heart rate is only one factor that determines physical fitness. You may also find that your heart rate will fluctuate throughout the day. Various kinds of food, stress, or a host of other factors can affect your heart rate.

Blood Pressure

Blood pressure is the force of the blood on the walls of the arteries. It can be measured indirectly with an instrument called a **sphygmomanometer** (**Figure 1**). A cuff with an air bladder is wrapped around the arm. A small pump is used to inflate the air bladder, thereby closing off blood flow through the brachial artery, one of the major arteries of the arm. A stethoscope is placed below the cuff and air is slowly released from the bladder until a low-pitched sound can be detected. The sound is caused by blood entering the previously closed artery.

sphygmomanometer a device used to measure blood pressure

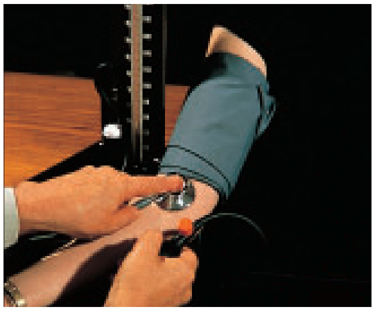


Figure 1
A sphygmomanometer

Each time the heart contracts, the sound is heard. A gauge on the sphygmomanometer measures the pressure exerted by the blood during ventricular contraction. This pressure is called systolic blood pressure. Normal systolic blood pressure is less than 120 mmHg (**Table 2**). (Blood pressure is measured in the non-SI units of millimetres of mercury, or mmHg.) The cuff is then deflated even more, until the sound disappears. At this point, blood flows into the artery during ventricular relaxation, or filling. This pressure is called diastolic blood pressure. Normal diastolic blood pressure is less than 80 mmHg. A systolic pressure of 120 mmHg and a diastolic pressure of 80 mmHg would be reported as 120/80 (120 over 80). Reduced filling, such as that caused by an internal hemorrhage, will cause diastolic blood pressure to fall. **Figure 2** shows that fluid pressure decreases with distance from the ventricles; thus, blood pressure readings are not the same in all arteries.

Table 2 Blood Pressure Categories (for 18 years and older)

	Blood Pressure (mmHg)	
Category	**Systolic**	**Diastolic**
normal	< 120	< 80
pre-hypertensive	120 to 139	80 to 89
hypertensive		
stage 1	140 to 159	90 to 99
stage 2	≥ 160	≥ 100

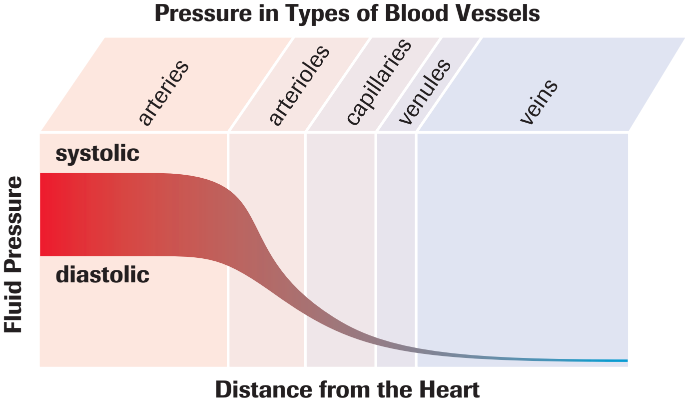


Figure 2
Fluid pressure decreases the farther blood moves from the heart.

Blood pressure depends on two factors. The first is cardiac output. Any increase in cardiac output will increase blood pressure. Another factor is arteriolar resistance. The diameter of the arteriole is regulated by smooth muscles. Constriction of the smooth muscles surrounding the arteriole closes the opening and reduces blood flow through the arteriole. With this reduced blood flow, more blood is left in the artery. The increased blood volume in the artery produces higher blood pressure. Conversely, factors that cause arteriolar dilation increase blood flow from the arterioles, thereby reducing blood pressure.

The smooth muscles in the walls of the arterioles respond to neural and hormonal controls that regulate blood pressure. The diameter of the arterioles also adjusts in response to metabolic products, such as those produced during the breakdown of glucose. When there is sufficient oxygen to break down glucose, carbon dioxide and water are produced. When there is insufficient oxygen, lactic acid is produced. Accumulation of carbon dioxide and lactic acid causes the relaxation of smooth muscles in the walls of the arterioles, dilating them. The dilated arterioles increase blood flow to local tissues, delivering more oxygen. Arteriolar dilation in response to increased metabolic

DID YOU KNOW?

Blood Pressure Units

The SI metric unit for blood pressure is the kilopascal (kPa). However, in medicine, blood pressure is still measured in millimetres of mercury (mmHg). (1 mmHg = 0.133 322 4 kPa)

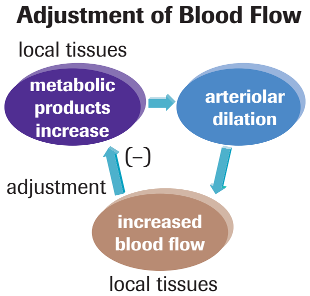


Figure 3
Control of arteriolar dilation

products is a good example of how the body maintains equilibrium (**Figure 3**). Activities such as exercise cause an increase in metabolic products. Because these products accumulate in the most active tissues, the increased blood flow helps provide greater nutrient supply and carries the potentially toxic materials away. Tissues that are less active produce fewer metabolic products. These arterioles remain closed until the products accumulate.

Hypertension: The Silent Killer

Hypertension (high blood pressure) is caused by increased resistance to blood flow, which results in a sustained increase in blood pressure. If blood pressure remains high, blood vessels are often weakened and may rupture. The body attempts to compensate for weakened vessels by increasing the support provided by connective tissues. Unfortunately, when the body increases the amount of connective tissue, arteries often become hard and less elastic. During systole, as blood pulses through these reinforced vessels, blood pressure increases more than usual, which in turn causes further stress and greater weakening.

Although hypertension is sometimes hereditary, diet is often a primary factor in the development of the disease. For example, in susceptible individuals, using too much salt can cause blood pressure to rise and the heart to work harder. Hypertension is often described as a silent killer because symptoms are usually not noticeable until the situation becomes very serious. A heart attack or stroke can be the first indication that something is wrong.

INVESTIGATION 10.2 *Introduction*

Effects of Posture on Blood Pressure and Pulse

Blood pressure is affected by factors such as exercise, drugs, and even posture. In this investigation, you will explore whether changes in body position cause measurable changes in blood pressure and/or pulse.

To perform this investigation, turn to page 344.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

Regulation of Blood Pressure

Regulation of blood pressure is essential since low blood pressure reduces your capacity to transport blood. The problem is particularly acute for tissues in the head, where blood pressure works against the force of gravity. High blood pressure creates equally serious problems. High fluid pressure can weaken an artery and eventually result in its rupture.

Special blood pressure receptors are located in the walls of the aorta and the carotid arteries, which are major arteries found on either side of the neck. These receptors are sensitive to high pressures. When blood pressure exceeds acceptable levels, the receptors respond to the increased pressure on the wall of the artery. A nerve impulse travels to the medulla oblongata, the blood pressure regulator located in the brainstem. Sympathetic (stress) nerve impulses are decreased and parasympathetic (relaxation) nerve impulses are increased. In reponse to decreasing sympathetic nerve stimulation, arterioles dilate, increasing the outflow of blood from the artery. Stimulation of the parasympathetic nerve causes heart rate and stroke volume to decrease. The decreased cardiac output slows the movement of blood into the arteries, lowering blood pressure.

CAREER CONNECTION

Cardiology Technologist
Cardiology technologists carry out diagnostic testing and monitoring of the heart, and ensure that pacemakers are working properly. They operate equipment during electrocardiograms, exercise stress tests, and echocardiograms. Are you interested in a career as a cardiology technologist?

www.science.nelson.com GO

Low blood pressure is adjusted by the sympathetic nerves. Without nerve information from the pressure receptors of the carotid artery and aorta, the sympathetic nerves will continue to be stimulated, causing cardiac output to increase and arterioles to constrict. The increased flow of blood into the artery accompanied by decreased outflow raises blood pressure to acceptable levels.

EXPLORE an issue

Pre-teens and High Blood Pressure

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

For many years, high blood pressure was associated primarily with men over 40 years of age. High blood pressure creates health problems due to the stress exerted on blood vessels and the heart itself. Heart disease is the number one killer of North Americans over age 40. Insufficient physical exercise, increased daily stress, and poor eating habits have made hypertension more common in women and younger adults.

Ironically, in an era when we know more about the causes and effects of high blood pressure, more people seem to be at risk of developing future health problems.

What is even more disturbing is that younger people today are likely even more susceptible to high blood pressure than their grandparents. A survey of 5000 pre-teens conducted by the Heart and Stroke Foundation indicated that most of them were aware of the benefits of physical exercise and of eating five to ten portions of fruit and vegetables each day. The vast majority also identified smoking as harmful for the heart. However, that same survey indicated that just over 50 % had engaged in some physical exercise that day, nearly 33 % had been exposed to second-hand smoke, and only 14 % had consumed four or more servings of fruit and vegetables. Virtual computer games were identified as the main competition for physical games, and fast foods were preferred to fruit and vegetables.

The rate of obesity among pre-teen boys nearly tripled between 1981 and 1996, while the obesity rate for girls more than doubled during the same time frame. The heart must work harder to pump blood through extra blood vessels in order to provide oxygen and nutrients to the new fat cells.

High blood pressure and obesity contribute to the development of type 2 diabetes. Aboriginal peoples have an increased risk of diabetes compared to the general population. Knowing the risk factors is important for everyone. Researchers have shown that type 2 diabetes, once associated with middle-aged men and women, is now found in overweight adolescents.

Statement

Health ministers across Canada know that money spent on prevention to change lifestyle behaviours is less costly than treating disease. Some people have even speculated about providing tax credits for leading a healthy lifestyle. How can a healthy lifestyle be promoted? Should people receive tax credits or pay less medical insurance? What responsibility do governments have in promoting a healthy lifestyle?

1. Form a group and research the issue.

   www.science.nelson.com GO

2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statements.
5. Defend your position in the debate.

Response of the Circulatory System to Exercise

Your body's response to exercise is an excellent example of how the body maintains equilibrium. Exercise places considerable demands on the circulatory system, but this system does not act alone in monitoring the needs of tissues or in ensuring that adequate levels of oxygen and nutrients are delivered to the active cells. The nervous and hormonal systems also play important roles in adjustment.

During times of stress, the sympathetic nerves stimulate the adrenal glands. The hormone epinephrine (adrenaline) is released from the adrenal gland and travels in the blood to other organs of the body. Epinephrine stimulates the release of red blood cells from the spleen. Although the significance of the response is not yet understood, it is clear that increased numbers of red blood cells aid oxygen delivery. Epinephrine and direct stimulation from the sympathetic nerves increase heart rate and breathing rate. The increased heart rate provides for faster oxygen transport, while the increased breathing rate ensures

that the blood contains higher levels of oxygen. Both systems work together to improve oxygen delivery to active tissues. A secondary but important function is the increased efficiency of waste removal from the active tissues.

Blood cannot flow to all capillaries of the body simultaneously. The effect of dilating all arterioles at one time would be disastrous—blood pressure would plunge. Only the most active tissues receive priority in times of stress. As a result, epinephrine causes vasodilation of the arterioles leading to the heart, brain, and muscles, preparing the organism for the flight-or-fight reaction. At the same time, the blood vessels leading to the kidney, stomach, and intestines constrict, depriving these areas of blood until the stress situation has been overcome.

Practice

1. What is hypertension?
2. How does exercise affect your heart rate? Provide an explanation for any change.
3. How does exercise affect your blood pressure? Provide an explanation for any change.
4. How is it possible that two different people have different pulses after doing exactly the same exercise?

INVESTIGATION 10.3 *Introduction*

Effects of Exercise on Blood Pressure and Pulse

How do you predict exercise will affect blood pressure and pulse? In this investigation, you will design and carry out a controlled experiment to test your prediction.

To perform this investigation, turn to page 344.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

Regulating Body Temperature

thermoregulation maintenance of body temperature within a range that enables cells to function efficiently

Thermoregulation is the maintenance of body temperature within a range that enables cells to function efficiently. Different species of animals are adapted to different temperature ranges, and each animal has an optimal temperature range. To understand the mechanisms of temperature regulation, we first need to consider the exchange of heat between the body and the environment.

Humans are able to maintain a constant body temperature regardless of their surroundings. The body adjusts to decreases in environmental temperatures by increasing the rate of cellular respiration to generate heat. In humans, normal body temperature is usually 37 °C; however, there is variation within any population. Studies indicate that body temperatures vary slightly during the day. Temperature in most individuals falls slightly during the night. It should also be noted that core temperatures and peripheral temperatures of the body tend to vary from each other. Core temperatures, found in the chest cavity, the abdominal cavity, and the central nervous system, remain relatively constant and are usually higher than 37 °C. The peripheral temperatures can be as much as 4 °C lower on very cold days.

DID YOU KNOW ?

Does Alcohol Warm You Up?

Many people believe that a drink of alcohol will warm them up on a cold day. Alcohol causes dilation of the arterioles leading to the skin capillaries, causing the sensation of warmth. However, the sensation is misleading. The dilation of these arterioles increases blood flow to the skin, which increases heat loss and speeds cooling.

Response to Temperature Stress

How does the body protect itself against excessive heat caused by exercise or high environmental temperatures? **Figure 4** shows what it does. When sensors in the brain detect a rise in body temperature, a nerve impulse is coordinated within the **hypothalamus**, and a signal is sent to the sweat glands to initiate sweating. The evaporation of perspiration from the skin causes cooling. At the same time, a nerve message is sent to the blood vessels in the skin, causing them to dilate. This allows more blood flow to the skin. Since the skin has been cooled by the evaporation of sweat, the blood loses heat to the skin. When blood from the skin returns to the core of the body, it cools the internal organs. Along with water, valuable salts are also carried to the skin's surface and lost with perspiration.

hypothalamus region of a vertebrate's brain responsible for coordinating many nerve and hormone functions

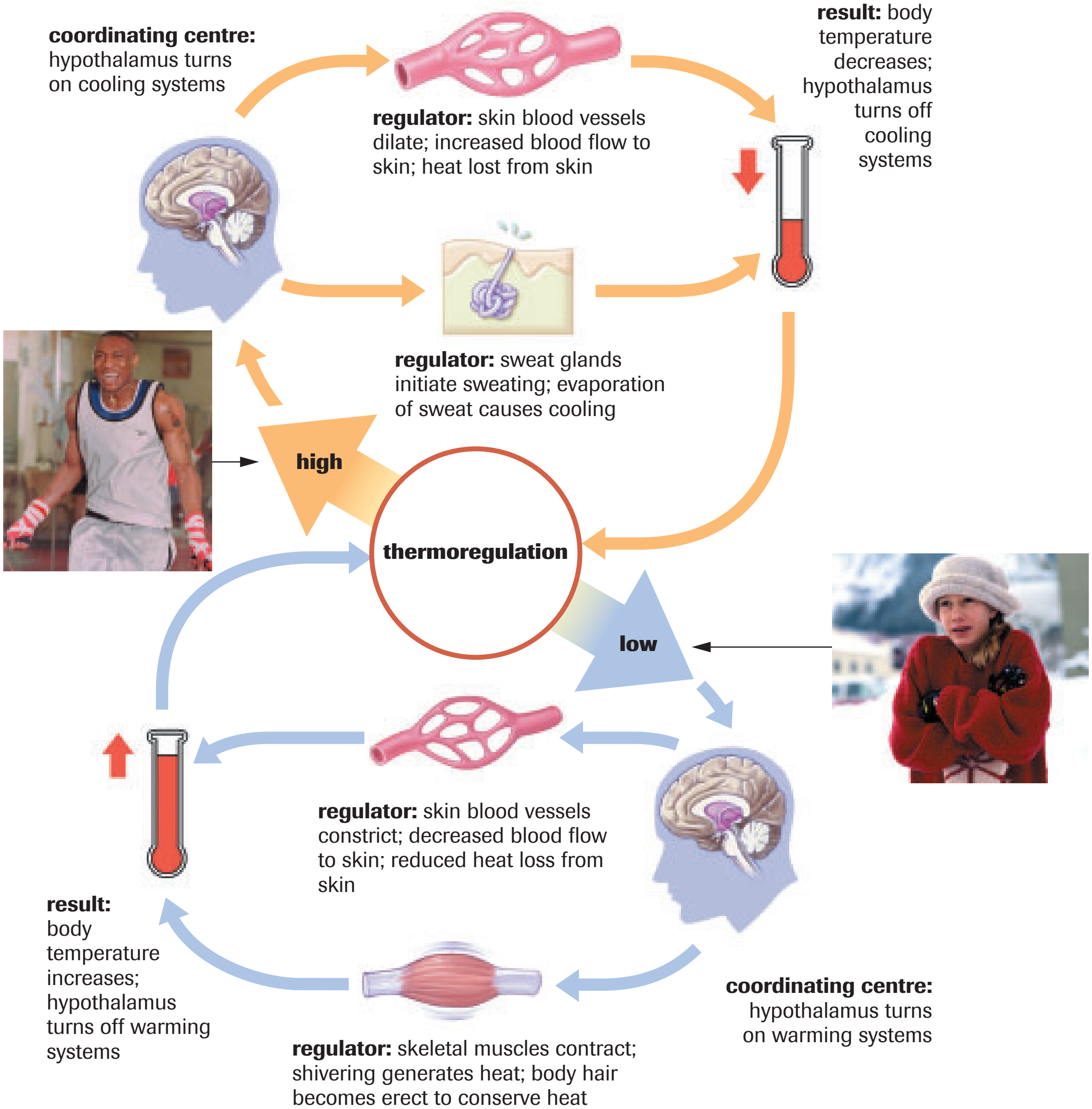


Figure 4

The evaporation of sweat and dilation of blood vessels provide a negative feedback response that cools the body. The constriction of blood vessels, shivering, and erection of the body hairs provide a negative feedback response that helps conserve heat.

In many ways, your response to cold mirrors your response to heat (**Figure 4**, previous page). When external temperatures drop, thermoreceptors in the skin send a message to the hypothalamus. Acting as a coordinating centre, the hypothalamus sends messages to the organs and tissues to increase body temperature. Nerves going to the arterioles of the skin cause smooth muscles to contract and the arterioles to constrict, limiting blood flow. This reduces heat loss from the skin and retains heat in the core of the body.

Nerve messages are also carried to the smooth muscle that surrounds the hair follicles in your skin, causing the hair to stand on end. The small bump made by the contraction of the muscle attached to the hair is often called a "goosebump." The erect hair traps warm, still air next to the surface of your skin and helps reduce heat loss. This response is particularly effective in mammals with a thick coat of body hair.

In addition, the hypothalamus also sends nerve messages that initiate shivering. The shivering response is a rhythmic contraction of skeletal muscle. Cycles of rapid muscle contractions of between 10 and 20 times per minute generate heat production by increasing metabolism.

Prolonged exposure to cold can create a hormonal response that also elevates metabolism. This type of heat production is most often associated with special adipose tissue called brown fat. Although its role in humans remains controversial, brown fat is especially capable of converting chemical energy into heat. Brown fat is important in newborns because they lack the ability to shiver. Babies have a small amount of brown fat in their neck and armpits and near their kidneys that insulates and generates heat.

Hypothermia is a condition in which the body's core temperature falls below the normal range. A drop in temperature of only a few degrees can lead to a coma and possibly death. However, some people, mainly small children, have survived sustained exposure to cold temperatures. This is often explained by the mammalian diving reflex. When a mammal is submerged in cold water, the heart rate slows and blood is diverted to the brain and other vital organs to conserve heat.

DID YOU KNOW ?

Self-Healing Behaviour

It has been discovered that sick lizards can intentionally give themselves a fever by resting in hot, sunny places. This behaviour raises their temperature to a slightly higher level, and the resulting fever helps fight infection.

SUMMARY Regulation of Blood Flow

- Cardiac output is the amount of blood the heart can pump each minute.
- Blood pressure is the force of blood on the walls of the arteries. It is measured as systolic and diastolic blood pressure in millimetres of mercury (mmHg).
- Blood pressure is higher in vessels closer to the heart.
- Increased cardiac output increases blood pressure. If arteries are constricted, blood flow is slower and blood pressure is higher.

Table 3 Summary of Stimulus–Response in Thermoregulation

Stimulus	Physiological response	Result
decreased environmental temperature	• constriction of blood vessels in skin • body hairs become erect • shivering	• heat is conserved • more heat is generated by increased metabolism
increased environmental temperature	• dilation of blood vessels of skin • sweating	• heat is dissipated

Section 10.3 Questions

1. How does stroke volume affect cardiac output?
2. How do metabolic products affect blood flow through arterioles? What causes the accumulation of metabolic products and where is accumulation most likely to occur?
3. Referring to the sympathetic and parasympathetic nerves, outline the adjustments to high blood pressure that help maintain equilibrium.
4. Would you expect blood pressure readings in all the major arteries to be the same? Explain your answer.
5. Why is systolic pressure lower when you are lying down than when you are standing up?
6. Why might diastolic blood pressure decrease as heart rate increases?
7. How do "goosebumps" help protect against rapid cooling?
8. What behavioural adjustments affect thermoregulation?
9. Explain why oral and rectal thermometers can give different readings.
10. Heat exhaustion caused by a person's exposure to heat can result in weakness or collapse. It usually involves a decrease in blood pressure. Explain why the thermoregulatory adjustment to heat can cause a drop in blood pressure.
11. The maximum suggested temperature of the water in a hot tub is about 38 °C. A higher temperature can seriously increase the risk of heat stroke. Explain why people will collapse in a hot tub set at 45 °C, but can survive temperatures of over 120 °C in heated rooms.
12. In **Figure 5 (a)**, beginning at the box labelled "increase in body temperature," replace the letters with the following feedback mechanisms for temperature control by the body: sweating, shivering, adjustment, evaporation. Do the same in **Figure 5 (b)**, beginning at the box labelled "decrease in body temperature."

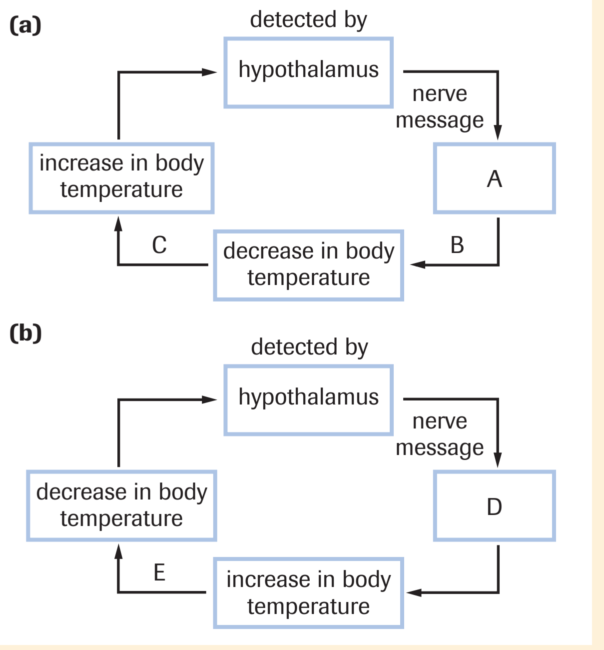


Figure 5

13. Arteriosclerosis is a group of disorders that can cause high blood pressure. How could lifestyle choices (e.g., related to nutrition or exercise) be changed to lessen a person's likelihood of getting the disorder?
14. Use the Internet or library to research how rapid cooling of the organs and tissues is used for surgery.

www.science.nelson.com GO

15. Drugs such as ecstasy interfere with the feedback mechanism that helps maintain a constant body temperature. Explain why these drugs are dangerous.

10.4 Capillary Fluid Exchange

extracellular fluid (ECF) fluid that occupies the spaces between cells and tissues; includes plasma and interstitial fluid

It is estimated that nearly every tissue of the body is within 0.1 mm of a capillary. Capillaries provide cells with oxygen, glucose, and amino acids and are associated with fluid exchange between the blood and surrounding **extracellular fluid (ECF)**. Most fluids simply diffuse through capillaries, whose cell membranes are also permeable to oxygen and carbon dioxide. Water and certain ions are thought to pass through spaces between the cells of the capillary while larger molecules and a very small number of proteins are believed to be exchanged by endocytosis or exocytosis. This section will focus on the movement of water molecules.

filtration the selective movement of materials through capillary walls by a pressure gradient

Two forces regulate the movement of water between the blood and ECF: fluid pressure and osmotic pressure. The force that blood exerts on the wall of a capillary is about 35 mmHg at the arteriole end of the capillary and approximately 15 mmHg at the venous end. The reservoir of blood in the arteries creates pressure on the inner wall of the capillary. Much lower pressure is found in the ECF. Although fluid bathes the cells, no force drives the extracellular fluid. Water moves from an area of higher pressure, the capillary, into an area of lower pressure, the ECF (**Figure 1**). The outward flow of water and small mineral ions is known as **filtration**. Because capillaries are selectively permeable, large materials such as proteins, red blood cells, and white blood cells remain in the capillary.

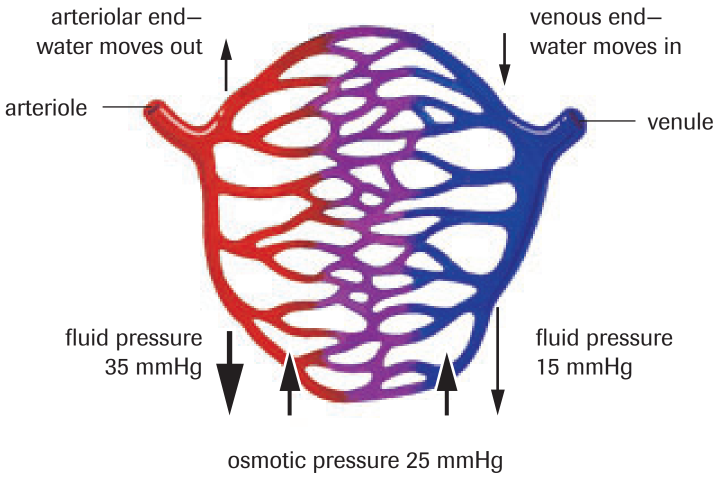
The movement of fluid out of the capillary must be balanced with a force that moves fluid into the capillary. The fact that large proteins are found in the blood but not in the ECF may provide a hint as to the nature of the second force. Osmotic pressure draws water back into the capillary. The large protein molecules of the blood and dissolved minerals are primarily responsible for the movement of fluid into capillaries. The movement of fluid into capillaries is called absorption. Osmotic pressure in the capillaries is usually about 25 mmHg, but it is important to note that the concentration of solutes can change with fluid intake or excess fluid loss caused by perspiration, vomiting, or diarrhea.

EXTENSION

Capillary Forces

In this animation, take a closer look at how fluid is moved in and out of capillaries by various forces.

www.science.nelson.com GO



Arteriolar end	
osmotic pressure	25 mmHg
fluid pressure	35 mmHg
absorption	–10 mmHg

Venous end	
osmotic pressure	25 mmHg
fluid pressure	15 mmHg
absorption	+10 mmHg

Figure 1
Fluid movement into and out of the capillaries

Application of the capillary exchange model provides a foundation for understanding adjustments that maintain equilibrium (**Figure 2**). The balance between osmotic pressure and fluid pressure is upset during a hemorrhage (excessive bleeding). The decrease in blood volume resulting from the hemorrhage lowers blood pressure. Although proteins are lost with the hemorrhage, so are fluids. Fewer proteins are present, but the concentration has not been changed. The force that drives fluid from the capillaries diminishes, but the osmotic pressure, which draws water into the capillaries, is not altered. The force drawing water from the tissues and ECF is greater than the force pushing water from the capillary. The net movement of water into the capillaries maintains equilibrium. As water moves into the capillaries, fluid volume is restored.

EXTENSION

Nutrient and Waste Exchange

Fluid movement into and out of the capillaries greatly improves the efficiency of nutrient and waste exchange between the blood and the tissues. Listen to this Audio Clip for a deeper understanding of this process.

www.science.nelson.com GO

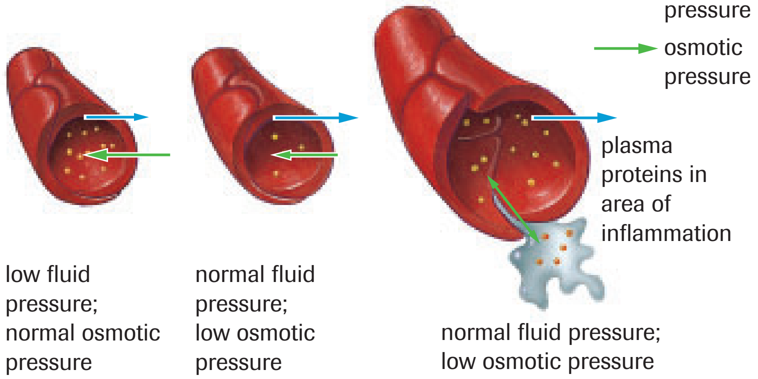


Figure 2
The balance between osmotic pressure and fluid pressure is upset during a hemorrhage, starvation, or inflammation.

Individuals who are suffering from starvation often display tissue swelling, or edema. Plasma proteins are often mobilized as one of the last sources of energy. The decrease in concentration of plasma proteins has a dramatic effect on osmotic pressure, which draws fluids from the tissues and ECF into the capillaries. The decreased number of proteins lowers osmotic pressure, thereby decreasing absorption. More water enters the tissue spaces than is pulled back into the capillaries, causing swelling.

Practice

1. Is fluid pressure greater in the arterioles or in the venules? Give reasons.
2. Is fluid pressure inside the capillary greater or less than the pressure in the ECF? How does this affect the movement of water?
3. What process allows water to flow out of the capillary but keeps proteins, red blood cells, and white blood cells inside the capillary?

The Lymphatic System

Normally, a small amount of protein leaks from capillaries to tissue spaces. Despite the fact that the leak is very slow, the accumulation of proteins in the ECF would create a major problem: osmotic pressure would decrease and tissues would swell.

The proteins are drained from the ECF and returned to the circulatory system by way of another network of vessels: the lymphatic system (**Figure 3**, next page). **Lymph**, a fluid similar to blood plasma, is transported in open-ended lymph vessels that are similar to veins. This low-pressure return system operates by slow muscle contractions against the vessels, which are supplied with flaplike valves that prevent the backflow of fluids. Eventually, lymph is returned to the venous system via the right and left subclavian veins.

lymph the fluid found in lymph vessels that contains some proteins that have leaked through capillary walls

lymph node a mass of tissue that stores lymphocytes and removes bacteria and foreign particles from the lymph

lymphocyte a white blood cell that produces antibodies

Enlargements called **lymph nodes** are located at intervals along the lymph vessel (**Figure 3**). These house white blood cells that, by the process of phagocytosis, filter out any bacteria that might be present. The lymph nodes also filter damaged cells and debris from the lymph and store **lymphocytes**. The lymph nodes in your neck sometimes swell when you have a sore throat.

Lymphoid Organs

Red bone marrow (**Figure 3**) is where all types of blood cells are produced. Stem cells, which are contained in the marrow, divide at incredible rates and differentiate into different types of white blood cells to meet the needs of the body. These specialized blood cells enter the circulatory system from a variety of sinuses. In children, red bone marrow is found in most bones; by adulthood, however, the cranium, sternum (breastbone), ribs, spinal column, and the long bones of the arms and legs have become the primary locations for blood cell production.

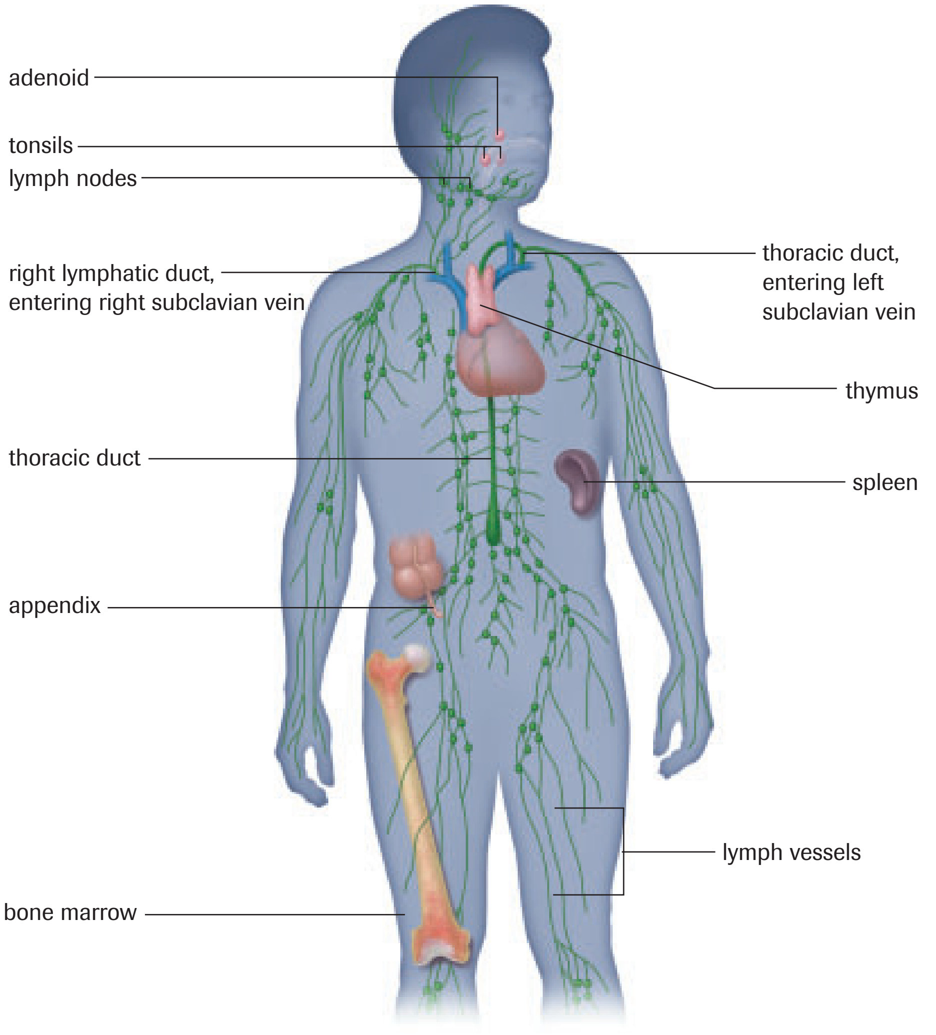


Figure 3
The lymphatic system. Debris is filtered out from the lymph, and the lymph is returned to the circulatory system.

CAREER CONNECTION

Registered Nurse

Registered nurses perform many duties, including administering medications, assisting surgeons, supervising nursing programs, treating illness and injury, and assessing/monitoring patient symptoms and reactions. Find out more about this exciting and challenging career.

www.science.nelson.com GO

The **spleen** is one of the body's largest lymphoid organs (**Figure 3**, previous page). Located in the upper left side of the abdominal cavity, just below the diaphragm, the spleen is richly supplied with blood sinuses. The sinuses allow the spleen to hold approximately 150 mL of blood, making it an excellent blood reservoir. The spleen releases red blood cells in response to low blood pressure or when blood oxygen levels drop dramatically.

spleen a lymphoid organ that acts as a reservoir for blood and a filtering site for lymph

The **thymus gland** is one of the few glands that tends to get smaller with age. Located in front of the trachea, just above the heart, the thymus gland is where T lymphocytes, or T cells, mature (**Figure 3**). The T cells that are released from the thymus gland have been selected to ensure that they will not initiate an immune response against the body's own proteins.

thymus gland a lymphoid organ in which T lymphocytes mature

SUMMARY Capillary Fluid Exchange

- Capillaries are associated with fluid exchange between blood and the extracellular fluid (ECF).
- The movement of water between blood and the ECF is regulated by fluid pressure and by osmotic pressure.
  - Water moves from an area of high fluid pressure, the capillary, to an area of low fluid pressure, the ECF.
  - Proteins and dissolved minerals in the blood cause fluid from the ECF to move into the blood by osmosis.
- Proteins in the ECF are returned to the circulatory system by the lymphatic system.
- Lymph nodes house white blood cells that filter bacteria.
- Red bone marrow is where all types of blood cells are produced.
- The spleen stores and purifies blood. The spleen releases red blood cells in response to low blood pressure or low oxygen levels in blood.

Section 10.4 Questions

1. What two factors regulate the exchange of fluid between capillaries and ECF?
2. Use the capillary exchange model to explain how the body maintains equilibrium following a hemorrhage.
3. Why does a low concentration of plasma protein cause edema?
4. What are lymph vessels and how are they related to the circulatory system?
5. What is lymph? How is lymph transported in the body? Where does lymph eventually go?
6. Why are lymphocytes important to the immune system?
7. What is the importance of the spleen?

INVESTIGATION 10.1

Fetal Pig Dissection

Like humans, the pig is a placental mammal, meaning that the fetus receives nourishment from the mother through the umbilical cord. Because the anatomy of the fetal pig resembles that of other placentals, this laboratory serves two important functions. It provides an overview of vertebrate anatomy and provides the framework for understanding functioning body systems.

Read and follow the procedure carefully. Accompanying diagrams are included for reference only. Use the appropriate dissecting instruments. This activity has been designed to minimize the use of a scalpel.

Report Checklist

● Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Materials

safety goggles	string	dissecting pins
lab apron	scalpel	scissors
dissecting gloves	hand lens	ruler
preserved fetal pig	dissecting tray	forceps and probe

Wear safety goggles and an apron at all times.

Wear plastic gloves when handling the preserved specimen and when performing a dissection to prevent any chemicals from coming in contact with your skin.

Wash all splashes of preservative from your skin and clothing immediately. If you get any chemical in your eyes, rinse for at least 15 min.

Work in a well-ventilated area. To reduce your exposure to any fumes from the preservative, make sure to avoid placing your face directly over the dissecting tray.

When you have finished the activity, clean your work area, wash your hands thoroughly, and dispose of all specimens, chemicals, and materials as instructed by your teacher.

Procedure

Part 1: External Anatomy

1. Place your pig in a dissecting tray. Use **Figure 1** to help you identify the four regions of the pig's body: the head, the neck, the trunk, and the tail.
2. Place the pig on its back (dorsal surface) and observe the umbilical cord.

Part 2: Abdominal Cavity

During the dissection, you will be directed to examine specific organs as they become visible. Remove only those organs indicated by the dissection procedure. Proceed cautiously to prevent damaging underlying structures.

3. With the pig still on its dorsal surface, attach one piece of string to one of the pig's hind legs, pull it under the dissecting pan, and tie it to the other hind leg. Repeat the procedure for the forelegs.
4. Using scissors, make the incision indicated as 1 in **Figure 2**. Start by cutting around the umbilical cord, and then cut straight toward the anterior (head) of the pig.

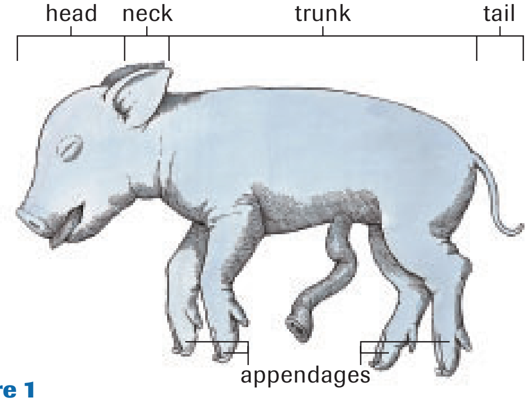


Figure 1
Regions of the body

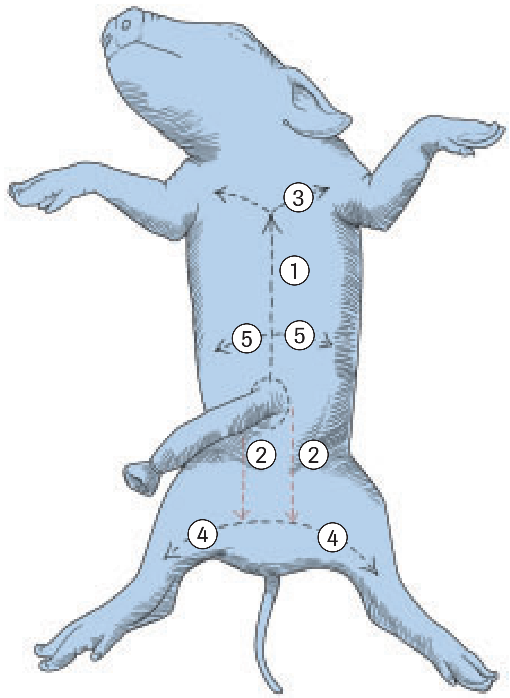


Figure 2
Ventral view of a fetal pig

5. Make incision 2 toward the posterior (tail) of the pig. Make incision 3 near the neck, and then incision 4. Make lateral incision 5; this incision runs parallel to the diaphragm, which separates the thoracic (chest) cavity from the abdominal cavity.
6. Pull apart the flaps along incision 5, exposing the abdominal cavity (**Figure 3**). Use the probe to open the connective tissue (peritoneum) that holds the internal organs to the lining of the body cavity. Now pull apart the flaps of skin covering incision 4 to expose the posterior portion of the abdominal cavity. Use pins to hold back the flaps of skin.
7. Locate the liver near the anterior of the abdominal cavity. Record the number of lobes in the liver.
8. Using a probe, lift the lobes and locate the saclike gallbladder. Describe the location of the gallbladder.
9. Follow the thin duct from the gallbladder to the coiled small intestine. Bile salts, produced in the liver, are stored in the gallbladder. The bile duct conducts the fat-emulsifying bile salt to the small intestine.
10. Locate the J-shaped stomach beneath the liver. Using forceps and a probe, lift the stomach and locate the esophagus attached near its anterior end. Locate the small intestine at the posterior junction of the stomach. The coiled small intestine is held in place by mesentery (a thin, somewhat transparent, connective tissue). Note the blood vessels that transport digested nutrients from the intestine to the liver.
11. Using a probe and forceps, lift the junction between the stomach and small intestine, removing supporting tissue. Uncoil the junction and locate the creamy-white pancreas. The pancreas produces a number of digestive enzymes and a hormone called insulin, which helps regulate blood sugar. Describe the appearance of the pancreas.
12. Locate the spleen, the elongated organ found around the outer curvature of the stomach. The spleen stores red and white blood cells. The spleen also removes damaged red blood cells from the circulatory system.
13. Using a scalpel, remove the stomach from the pig by making transverse (crosswise) cuts near the junction of the stomach and the esophagus, and near the junction of the stomach and small intestine. Make a cut along the midline of the stomach, and open the cavity. Rinse as instructed by your teacher. View the stomach under a hand lens. Describe the appearance of the inner lining of the stomach.

Part 3: Thoracic Cavity

14. Carefully fold back the flaps of skin that cover the thoracic cavity. You may use dissecting pins to attach the ribs to the dissecting tray. List the organs found in the thoracic cavity (**Figure 4**, next page).
15. Locate the heart. The coronary vessels carry blood to and from the heart itself (**Figure 5 (a)**, next page). Using forceps and a probe, remove the pericardium (a thin connective tissue covering the heart) from the outer surface of the heart.

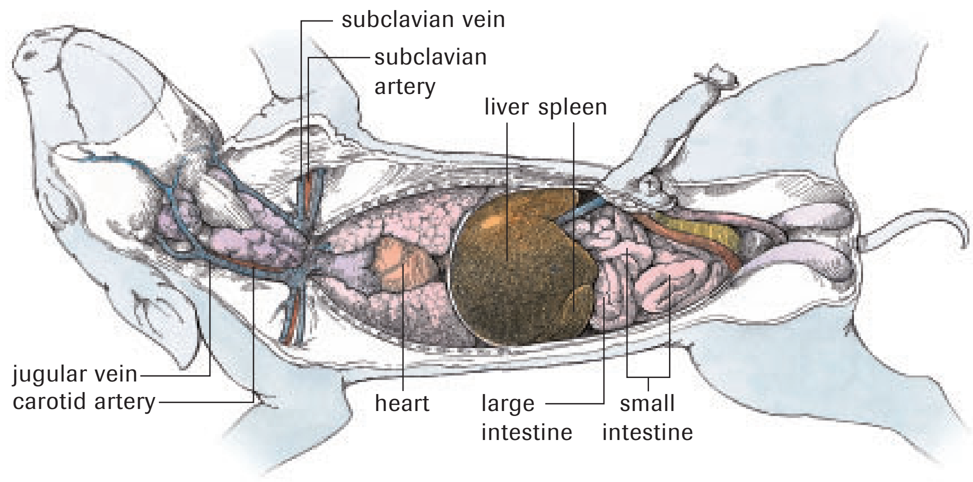
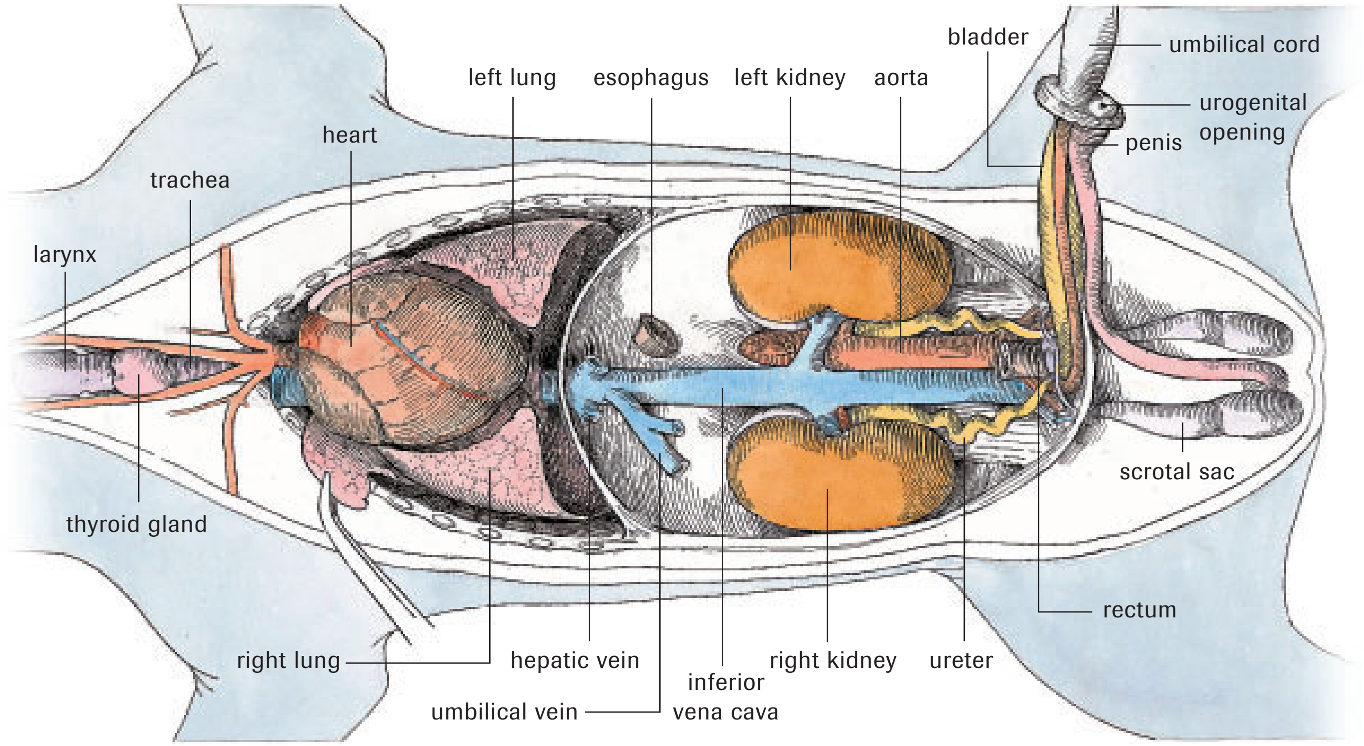


Figure 3
Abdominal cavity and thoracic cavity of the fetal pig. Organs of the digestive system and circulatory system are highlighted in the diagram.

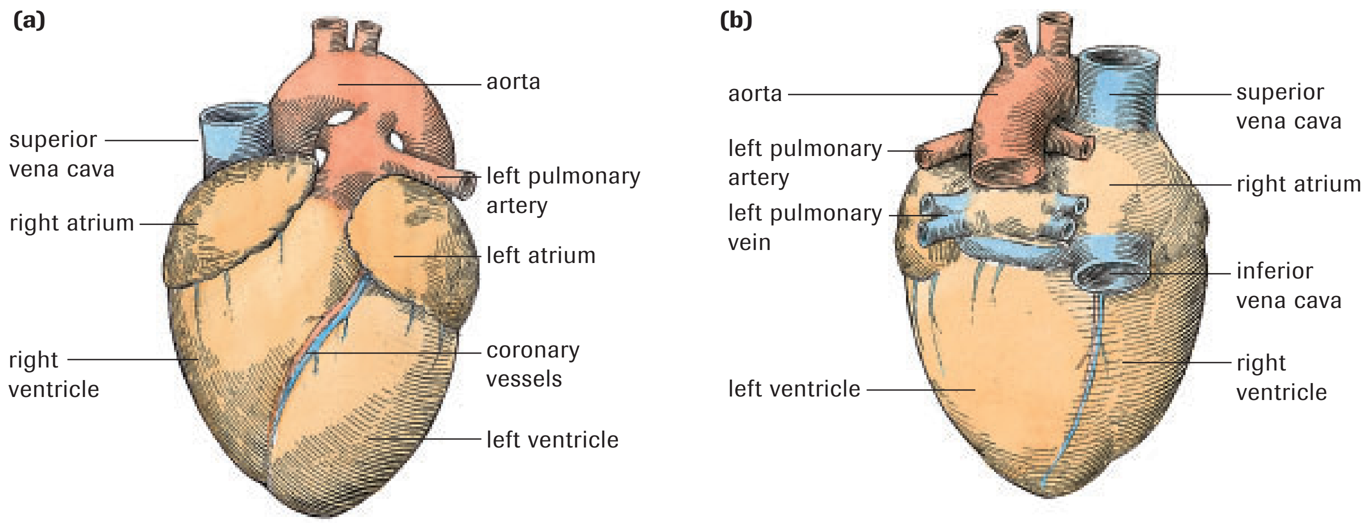
INVESTIGATION 10.1 *continued*

Figure 4
Thoracic cavity and urogenital system



16. Blood from the head and upper body enters the right side of the heart through the superior vena cava. The large blood vessel that carries blood from the lower parts of the body to the right side of the heart is called the inferior vena cava (**Figure 5** (**b**)). (The right side refers to the pig's right side.) Both the superior and inferior venae cavae are considered to be veins because they bring blood to the heart. Locate the superior and inferior venae cavae.

Figure 5
(a) Ventral view of the heart
(b) Dorsal view of the heart



17. Trace blood flow through the heart. Blood entering the right side of the heart collects in the right atrium. Blood from the right atrium is pumped into the right ventricle. Upon contraction of the right ventricle, blood flows to the lungs by way of the pulmonary artery. Arteries carry blood away from the heart. Blood, rich in oxygen, returns from the lungs by way of the pulmonary veins and enters the left atrium. Blood is pumped from the left atrium to the left ventricle and out the aorta.
18. Make a diagonal incision across the heart and expose the heart chambers. Compare the thickness of the wall of a ventricle to that of an atrium.
19. Locate the spongy lungs on either side of the heart and find the trachea leading into the lungs (**Figure 6**).
20. Place your index finger on the trachea and push downward. Describe what happens.

Analysis and Evaluation

(a) What is the function of the umbilical cord?

(b) State the function of the following organs: stomach, liver, small intestine, gallbladder, pancreas, large intestine, and spleen.

(c) What is the function of the mesentery?

(d) Why does the left ventricle contain more muscle than the right ventricle?

(e) Why do the lungs feel spongy?

(f) What function do the cartilaginous rings of the trachea serve?

(g) Make labelled diagrams of the following:
- digestive system
- heart and the blood vessels associated with it
- respiratory system

(h) Write a report in which you point out the similarities and differences between the anatomy of a pig and a human.

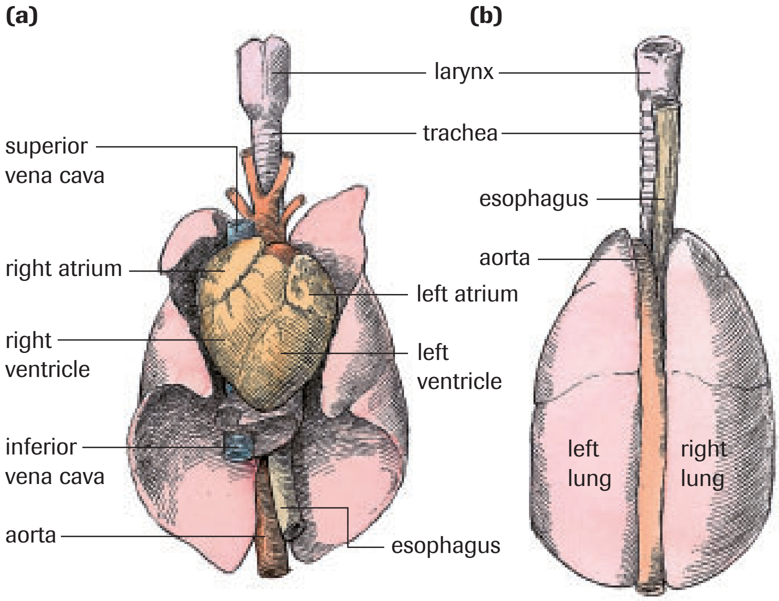


Figure 6
(a) Ventral view of heart and lungs
(b) Dorsal view of lungs

INVESTIGATION 10.2

Effects of Posture on Blood Pressure and Pulse

Blood pressure is affected by factors such as exercise, drugs, and even posture.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To determine the effect of posture on blood pressure and pulse

Materials

sphygmomanometer

watch with second hand

Procedure

1. Ask your partner to sit quietly for 1 min.
2. Expose your partner's arm and place the cuff of the sphygmomanometer just above the elbow.
3. Close the valve on the rubber bulb. Inflate the cuff by squeezing the rubber bulb until a pressure of 180 mmHg registers.
4. Release the pressure by opening the valve on the sphygmomanometer and watch the readout. Record the systolic and diastolic blood pressures.

Do not leave the pressure on for longer than 1 min. If you are unsuccessful, release the pressure and try again on the opposite arm.

5. Completely deflate the cuff. If you are not using an electronic sphygmomanometer that provides the pulse, take and record your partner's pulse. Place your index and middle fingers on the inside arm near the wrist. Count the number of pulses in 1 min.
6. Repeat Steps 2 to 5 while your partner is in a standing position and then in a lying position.

Analysis

(a) Which varied more with the change in posture: systolic blood pressure or diastolic blood pressure? Explain.

(b) What factors other than posture might have contributed to the change in blood pressure?

INVESTIGATION 10.3

Effects of Exercise on Blood Pressure and Pulse

In this investigation, you will design and perform a controlled experiment to test the effects of exercise on blood pressure and pulse. Once your teacher has approved your design, carry out your procedure and record the evidence. You will then analyze the evidence to state how exercise affected blood pressure and pulse. In your lab report, include answers to the Evaluation questions.

Do not perform this activity if you are not allowed to participate in physical education classes.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To determine the effects of exercise on blood pressure and pulse

Design

Your design must include:

- descriptions of the manipulated, responding, and controlled variables
- a step-by-step procedure
- a list of safety precautions
- an appropriate method to record the evidence

Evaluation

(a) Describe any problems or difficulties in carrying out the procedure.

(b) How could you improve your current design?

Chapter 10 SUMMARY

Outcomes

Knowledge

- identify the principal structures of the heart and associated blood vessels, i.e., atria, ventricles, septa, valves, aorta, vena cavae, pulmonary arteries and veins, and sinoatrial node, atrioventricular node, Purkinje fibres (10.2)
- describe the action of the heart, blood pressure, and the general circulation of the blood through coronary, pulmonary, and systemic pathways (10.2)
- describe the structure and function of blood vessels, i.e., arteries, veins, and capillaries (10.1)
- explain the role of the circulatory system at the capillary level in aiding the digestive, excretory, respiratory, and motor systems' exchange of energy and matter with the environment (10.3)
- explain the role of blood in regulating body temperature (10.3)
- explain how the motor system supports body functions, i.e., circulatory (10.1)
- describe and explain, in general terms, the function of the lymphatic system (10.4)

STS

- explain how Canadian society supports scientific research and technological development (10.2)
- explain that decisions regarding the application of scientific and technological developments involve a variety of perspectives, including social, cultural, environmental, ethical, and economic considerations (10.2)

Skills

- ask questions and plan investigations (10.3)
- conduct investigations and gather and record data and information by: measuring blood pressure (10.3) and observing blood flow in capillaries in a living organism or through demonstration in a virtual lab (10.1); selecting and integrating information to observe the principal features of a mammalian circulatory system and the direction of blood flow, and identifying structures from drawings (10.2) and; observing, through dissection or computer simulations, the respiratory and digestive systems of a representative mammal and identifying the major structural components (10.2)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

10.1

artery
pulse
autonomic nervous system
vasoconstriction
vasodilation
atherosclerosis
arteriosclerosis
aneurysm
vein

10.2

septum
pulmonary circulatory system
systemic circulatory system
atrium
ventricle
atrioventricular (AV) valve
semilunar valves
aorta
coronary artery
myogenic muscle
sinoatrial (SA) node
atrioventricular (AV) node
Purkinje fibre
sympathetic nervous system
parasympathetic nervous system
diastole
systole

10.3

cardiac output
stroke volume
sphygmomanometer
thermoregulation
hypothalamus

10.4

extracellular fluid (ECF)
filtration
lymph
lymph node
lymphocyte
spleen
thymus gland

MAKE a summary

1. Create a concept map that shows how the circulatory system maintains an internal equilibrium. Label the concept map with as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 10
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Chapter 10 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The pacemaker of the heart is the
  A. Purkinje fibres
  B. sinoatrial node
  C. atrioventricular node
  D. semilunar node

2. The pulmonary artery
  A. carries oxygenated blood to the heart from the lungs
  B. carries deoxygenated blood to the heart from the lungs
  C. carries oxygenated blood away from the heart to the lungs
  D. carries deoxygenated blood away from the heart to the lungs

Use the following information to answer questions 3 and 4.

The oxygen content of the blood was monitored in different blood vessels as blood moved away from the heart. The results of the study are shown in **Figure 1**.

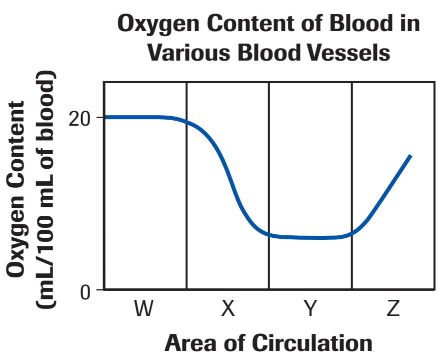


Figure 1

3. The area of the graph in **Figure 1** that would most likely represent capillaries within muscle cells would be
  A. W
  B. X
  C. Y
  D. Z

4. Identify the area of the graph in **Figure 1** where you would expect to find blood within a vein inside the brain.
  A. W
  B. X
  C. Y
  D. Z

Use the following information to answer questions 5 to 7.

Capillaries were observed within the tail of a fish. The capillaries were subjected to treatment with different chemicals, and the flow of blood cells through the capillary was observed 30 seconds later. **Table 1** shows the data that was collected.

Table 1 Blood Flow in Fish Tail Capillaries

Treatment	Average blood flow after treatment (cells/min)
control	60
epinephrine	40
lactic acid	90
alcohol	80
temperature reduced by 20 °C	30
nicotine	25

5. The number of blood cells that would normally pass through capillaries of the fish's tail at room temperature is
  A. 60 cells/min
  B. 40 cells/min
  C. 80 cells/min
  D. 30 cells/min

6. Nicotine is a drug found in cigarettes. Select the conclusion that is supported by the data provided in **Table 1**.
  A. Nicotine causes arteriolar constriction. Fewer blood cells move through capillaries after the treatment.
  B. Nicotine causes arteriolar constriction. More blood cells move through capillaries after the treatment.
  C. Nicotine causes constriction of the capillaries. Fewer blood cells move through capillaries after the treatment.
  D. Nicotine causes constriction of the capillaries. More blood cells move through capillaries after the treatment.

7. Lactic acid is produced in muscles during anaerobic respiration. Select the conclusion about lactic acid treatment that is supported by the data provided in **Table 1**.
  A. Lactic acid decreases blood flow to tissues. More oxygen is delivered to tissues, which decreases the amount of lactic acid in the blood.
  B. Lactic acid decreases blood flow to tissues. More oxygen is delivered to tissues, which increases the amount of lactic acid in the blood.
  C. Lactic acid increases blood flow to tissues. More oxygen is delivered to tissues, which decreases the amount of lactic acid in the blood.
  D. Lactic acid increases blood flow to tissues. More oxygen is delivered to tissues, which increases the amount of lactic acid in the blood.

8. Calculate the stroke volume of a person with a heart rate of 82 beats/min and a cardiac output of 4.6 L. (Record your answer as a value rounded to two decimal places.)
NR

Part 2

Use the following information to answer questions 9 to 11.

Figure 2 shows the chambers of the heart, and blood vessels entering and exiting the heart.

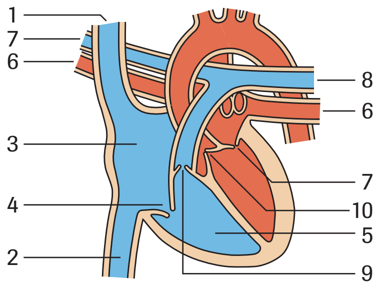


Figure 2

9. **Identify** the number(s) of the vein(s) that return blood to the heart from the body.
DE

10. **Identify** the number of the ventricle that contains deoxygenated blood.
DE

11. **Identify** the number of the heart valves that produce the *lubb* sound when closing.
DE

12. **Identify** differences in the structures of veins, arteries, and capillaries and **describe** how they are related to the functions of each vessel.

13. "Oxygenated blood is found in all arteries of the body." Is this statement true or false? Give reasons to **explain** your answer.

14. **Why** does the left ventricle contain more muscle than the right ventricle?

15. Arteriosclerosis is a condition referred to as "hardening of the arteries." It results from a reduction in the elasticity of the arteries. **Describe** two circulatory problems that might arise from this effect on the vessels.

16. The victim of an accident has had a large blood vessel severed and bleeding is severe. **How** does excessive bleeding endanger life? **Outline** in a list two physiological responses that will help the victim to survive.

17. **Why** does the blockage of a lymph vessel in the left leg cause swelling in that area?

Use the following information to answer questions 18 and 19.

Table 2 is a record of a person's blood pressure taken in a sitting position before and after exercise.

Table 2 Effect of Exercise on Blood Pressure and Pulse

Condition	Systolic blood pressure (mmHg)	Diastolic blood pressure (mmHg)	Pulse (beats/min)
resting	120	80	70
after exercise	180	45	160

18. **Why** does systolic blood pressure increase after exercise?
DE

19. **Why** does diastolic blood pressure decrease after exercise?
DE

20. **How** does the respiratory system depend on the circulatory system?

21. Nicotine causes the constriction of arterioles. Write a unified response that addresses the following aspects of smoking during pregnancy.
DE
- **Explain why** pregnant women are advised not to smoke.
- Mothers who smoke give birth to babies who are, on average, 1 kg smaller than normal. **Describe** a possible relationship between the effects of nicotine on the mother's circulatory system and the lower body mass of babies.

22. Heart disease is currently the number one killer of middle-aged males, accounting for billions of dollars every year in medical expenses and productivity loss. Should males be required by law to undergo heart examinations? **Justify** your answer. Consider the social and moral implications of such a law.

23. Caffeine causes heart rate to accelerate; however, a scientist who works for a coffee company has suggested that blood pressure will not increase due to coffee consumption. This scientist states that equilibrium adjustment mechanisms ensure that blood pressure readings will remain within an acceptable range. **Design** an experiment that will test the scientist's hypothesis. What other reasons might the scientist have for suggesting that caffeine does not increase blood pressure?